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U. S. DEPARTMENT OF AGRICULTURE.

OFFICE OF EXPERIMENT STATIONS—BULLETIN NO. 119.

A. C. TRUE, Director.

U. S. Office of experiment stations.

REPORT

OF

IRRIGATION INVESTIGATIONS FOR 1901.

UNDER THE DIRECTION OF

ELWOOD MEAD,

Chief of Irrigation Investigations.

CONTAINING SUMMARY OF RESULTS BY R. P. TEELE AND REPORTS BY W. M. REED, W. H. CODE, A. J. McCLATCHIE, E. W. HILGARD, W. IRVING, A. E. CHANDLER, O. L. WALLER, D W. ROSS, SAMUEL FORTIER, A. P. STOVER, O. V. P. STOUT, H. J. WATERS, F. H. KING, E. B. VOORHEES, AND J. C. NAGLE.

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LETTER OF TRANSMITTAL.

U. S. Department of Agriculture,
Office of Experiment Stations,
Washington, D. C., September 1, 1902.

Sir: I have the honor to transmit herewith a report of the irrigation investigations carried on by this Office during the season of 1901, under the direction of Prof. Elwood Mead, Chief of Irrigation Investigations, and to recommend its publication as a bulletin of this Office.

It gives the result of another season's investigations of the problems of irrigation which have been carried on along similar lines for three years past, the results obtained in previous years being reported in Bulletins 86 and 104 of this Office. The increasing demand for information on the subjects dealt with, as shown by the calls for the earlier reports and by application for this one in advance of its publication, shows that their value in the development of the West is being more and more recognized.

Respectfully,

A. C. True,
Director.

Hon. James Wilson,
Secretary of Agriculture.

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REPORT OF IRRIGATION INVESTIGATIONS, 1901.

SUMMARY OF RESULTS.

By R. P. TEELE, *Assistant in Irrigation Investigations.*

This report is the third of a series dealing with the duty of water in irrigation and the methods and measures for securing the largest and best use of the water supply, but taking up incidentally many other related questions. The duty of water was made the leading feature of one of the branches of irrigation investigations, because from any standpoint, administrative, engineering, or agricultural, the water commissioner, the engineer, or the farmer soon comes to the point where it is necessary to know approximately how much water is needed for an acre of ground.

Two States, Nebraska and Wyoming, have already passed laws limiting the quantity of water which may be appropriated for a given area, while all the other States where irrigation is necessary have laws prohibiting waste and limiting rights to water to the quantity which can be used beneficially. Those charged with the distribution of the water supply must know what is beneficial use and where waste begins. The measurements given in this and previous reports are intended to give a basis for answering these questions.

The irrigation engineer needs to know more than the theoretical carrying capacities of ditches of various sizes and grades, and the cost of excavation in different materials and of different classes of construction. He must know how much land the water carried by this canal will serve. The basis for all the computations of the engineer must be the quantity of water required for an acre planted to the crops which it is proposed to raise.

The farmer, at the very beginning of his experience with irrigation, must know how much water he needs and when he needs it. If he builds his own canal, he must know how large to make it; if he buys water from a large canal, he must know how much to buy. Building too large a canal or paying for more water than he needs is throwing money away, while farming with too little water is equally as disastrous. The tendency of farmers seems to be to use all the water that can be obtained, often to the injury of their crops and lands. Such farmers need to be shown the better results obtained by others who use water economically.

In the measurements so far made no attempt has been made to control the quantity of water used. The attempt has been to find out how much water is used under present practice, since that is what all who have to do with irrigation must deal with. It is the intention to make the investigations of the future deal more and more with what can be done by better methods and more economical use of water.

The measurements made the first year of the investigation showed great differences between the quantities of water entering canals and the quantities received by the land. This led to measurements to determine where these losses took place, as a basis for studying methods of preventing, or at least reducing, the losses. A few such measurements were reported in 1900, but a more comprehensive study was made in 1901. The results are given in the pages which follow. The increasing value of water and the definite knowledge as to quantities lost have brought out the fact that the saving of the water now lost would justify large expenditures for that purpose. In California, where water has a high value, owing to its scarcity and the value of crops raised, canals have been cemented, thus reducing the loss to 1 per cent or less. The same practice can profitably be extended to other regions in the Southern States, at least, and perhaps to the Northern States, although this is doubtful. The freezing of the ground in the latter section may prevent the use of cement. It may be found that in such places the saving would justify piping the water from the streams to the lands to be watered, or pumping it from points near the place of use, to avoid the loss from long canals passing through sandy and gravelly soils. The investigation so far has dealt only with the quantities lost and the places where the losses occur. The report of Mr. Irving (pp. 154–159) discusses the reasons which led to the cementing of the Gage Canal in California, and gives extracts from the specifications and contracts for the work.

The effects of the losses from canals are not limited to a diminution of the water supply. Large areas of land formerly farmed have been swamped, or the rise of the ground water has caused an accumulation of alkali which has killed out all useful vegetation. Methods of relieving this condition are discussed briefly in some of the reports which follow. A thorough study of such methods is now being carried on, the results of which will be included in future reports. The most efficient means, however, will be the removal of the cause, by preventing losses from canals and excessive use of water in irrigation.

In many places pumping from wells will be found the most satisfactory means of obtaining a water supply. For this reason the agents of this Office have been instructed to obtain data upon the efficiency of pumps and the cost of their installation and operation. Several of the reports which follow contain information on this subject, and on pages 33–35 all the data contained in this and the former publications of this Office have been brought together.

The field agents, whose reports are contained in this volume, in addition to measuring the quantities of water used and lost, have taken up the laws relating to irrigation, and the regulations and customs, which have a more intimate relation than the laws to the actual practice of farming by irrigation. In addition to these general lines, the agents have noted many interesting facts which refer to their particular sections, but have no general bearing.

Four stations have been maintained during the past year in sections of the country where farming operations have been carried on successfully for years without the aid of irrigation. In such sections irrigation is treated as any other means of increasing the returns from land. The question to be settled is whether the added expense of providing a water supply will be repaid with a profit. Having settled that, a study of the best methods of using water naturally follows. The work at the four stations in the humid region has included both phases referred to above. The stations are located in Nebraska, Missouri, Wisconsin, and New Jersey. Taking the humid region as a whole, irrigation has proven itself a profitable undertaking for everything except general farm crops. As population increases, more intensive farming becomes necessary, and the practice of supplying water to crops will undoubtedly grow. So far questions of rights to water have attracted no attention. There is, however, every reason to believe that such questions will arise as water is more and more used for irrigation. It is probably not possible to anticipate such controversies by amending the laws of the various States, but some of the evils which have been so disastrous in the Western States may be avoided by recognizing the fact that they are liable to arise.

For many years Prof. E. W. Hilgard, director of the Agricultural Experiment Station of California, has been engaged in a study of the water resources and irrigation problems of that State. Some of the results of these studies are given in this report in a paper on the water supplies and their utilization in the San Bernardino Valley, California, prepared under the cooperative arrangement which exists between that station and this investigation. While the scope of Professor Hilgard's report is somewhat outside of the regular work of these investigations, it is believed that this presentation of the results of his reseaches will be of great value to the people of the section dealt with.

The second progress report on the measurements of silt carried in the waters of several streams of the Southwest is also given in this volume. These measurements have been carried on for two years, but several years more must elapse before any conclusions are reached.

In the succeeding pages the reports of the agents and observers are summarized for the use of those who want only general results. Those who care for methods and details of the work, or for more

exact information regarding particular localities, are referred to the reports themselves.

DUTY OF WATER.

The measurements of the quantities of water used are divided into four classes: Measurements of (1) the quantity of water entering main canals; (2) the quantity of water entering laterals; (3) the quantity of water used on individual farms, and (4) the quantity of water used on separate crops.

MAIN CANALS.

The results of the measurements of the first class are of especial use to the builders of irrigation works, whether public or private. They show the quantity of water which must be diverted from a stream to reclaim an acre of ground, and hence are the basis for the computations of the promoter and also for the work of the engineer. The following table brings together all the measurements on main canals, which have so far been made by this Office. The canals are grouped by States:

Quantity of water used per acre under main canals, 1899–1901.

Name of canal.	1899.	1900.	1901.	Average.
Arizona:	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*
Arizona, Maricopa, and Salt canals		2.45	4.59	3.52
Utah Canal		2.49	4.93	3.71
Tempe Canal		2.88	4.06	3.47
Consolidated (Mesa water)		2.02	4.53	3.28
Mesa Canal	3.81	2.35		3.08
California:				
Gage Canal	2.24	2.23	2.00	2.16
Plano Ditch			7.91	7.91
Poplar Ditch			3.19	3.19
Pioneer Ditch			8.01	8.01
Pleasant Valley Ditch			6.31	6.31
South Tule Independent Ditch			7.46	7.46
Colorado:				
Amity Canal	4.92			4.92
Grand Valley Canal			4.11	4.11
Kiefer Extension of Grand Valley Canal			5.42	5.42
Lake Canal			2.58	2.58
Montana:				
Middle Creek Canal	2.10	1.90	2.34	2.11
Big Ditch		1.88		1.88
Republican Canal			3.35	3.35
Hedge Canal			3.97	3.97
Ward Canal			2.41	2.41
Skalkaho Canal			4.68	4.68
Gird Creek Canal			1.45	1.45
Nevada: Orr Ditch		7.08		7.08
Nebraska: Gothenberg Canal	2.57			2.57
New Mexico: Pecos Canal	6.61	6.99	10.09	7.90
Utah:				
Butler Ditch	6.24	5.18		5.71
Brown & Sanford Ditch	5.32	4.08		4.70
Upper Canal	6.30	3.92		5.11
Green Ditch	4.52	6.14		5.33
Lower Canal	2.83	3.06		2.95
Big Ditch	3.09	2.86		2.98
Logan and Richmond Canal	3.59	4.82		4.22
Tanner Ditch		3.62		3.62
Farr & Harper Ditch		5.77		5.77
Logan, Hyde Park, and Smithfield Canal		3.94		3.94
Bear River Canal			4.84	4.84
Washington:				
Prosser Canal		3.04	4.70	3.87
Sunnyside Canal	10.64	10.24	9.75	10.21
Wyoming: Canal No. 2, Wyoming Development Co.	2.53	4.90		3.72
Average	4.42	4.08	4.90	4.45

The table shows a very close agreement in the averages for the three years given. The excess for 1901 is due to the measurements of the Tule River canals, which are high, and were not included in the averages for the previous years. Leaving out these canals, the average for 1901 is 4.43 feet, or within 0.01 of the average for 1899. The low average of 1900 is partly due to the short water supply in the Salt River Valley in Arizona. The average for 1900, excluding the Salt River canals, is 4.54 feet, slightly more than the average for 1899. The last column gives the averages of all the measurements made on the canals named. Averaging these gives a depth of 4.45 feet as a general average for all the canals on which measurements have been made. The list includes canals of all ages and all degrees of efficiency. Some of the Utah canals have been in use for nearly half a century, while the Washington canals have been used for only a few years. The Gage Canal is cemented, so that there is practically no loss of water, while one of the Tule River canals is reported as losing in 2 miles more than 90 per cent of the water entering it. Furthermore, the canals are distributed widely enough to be representative of the whole arid region. The general average of 4.45 acre-feet must, therefore, be considered a very fair statement of the quantity of water which must be supplied at the head of a canal for each acre of land to be irrigated. Stated in another way: Where a known volume of water can be obtained, the area of land which can be irrigated with that supply will be 1 acre for every 4.45 acre-feet of water available. As has been stated, this represents present practice. It should not be considered as representing what is possible. In fact, the possibility of a much more economical use of the water supply is the basis for the hope of a great future expansion in many sections where the supply of water is already fully utilized. The smallest quantity given in the table is 1.45 acre-feet per acre, under the Gird Creek Canal, in Montana; the largest is 10.64 acre-feet per acre, under the Sunnyside Canal, in Washington. If the latter locality could get along with as little water as the former, the water used under the Sunnyside Canal would serve about seven times the area now farmed. Both these canals are extremes, but the comparison serves to indicate the line along which expansion can be made.

LATERALS.

The following table gives all the measurements at the heads of laterals which have been made by this Office in the three years covered by the investigations:

Quantity of water used per acre under laterals.

Canal.	Lateral.	Year.	State.	Quantity.
				Acre-feet.
Pioneer Canal	Flume lateral No. 2	1901	California	1.41
Amity Canal	Biles lateral	1899	Colorado	1.82
Lake Canal	Lewis lateral	1901	....do	3.11
Ridenbaugh Canal	Rust lateral	1899	Idaho	5.06
Do	.....do	1901	.....do	6.49
Do	Crawford lateral	1901	.....do	3.38
Do	Huntington lateral	1901	.....do	3.04
Do	Creeson lateral	1901	.....do	4.48
Do	Hunter lateral	1901	.....do	4.24
Do	Rutledge lateral	1901	.....do	3.90
Do	Tuttle lateral	1901	.....do	5.47
Do	Pollard lateral	1901	.....do	3.81
Do	Clark lateral	1901	.....do	4.64
Do	Perkins lateral	1901	.....do	4.49
Do	Brose lateral	1901	.....do	5.93
Pecos Canal	Division No. 1	1899	New Mexico	6.51
Do	Division No. 2	1899	.....do	4.53
Do	Division No. 3	1899	.....do	2.95
Do	Division No. 4	1899	.....do	3.56
Do	Division No. 1	1900	.....do	4.65
Do	Division No. 2	1900	.....do	3.39
Do	Division No. 3	1900	.....do	2.48
Do	Division No. 4	1900	.....do	2.27
Do	Division No. 1	1901	.....do	5.11
Do	Division No. 2	1901	.....do	3.91
Do	Division No. 3	1901	.....do	3.02
Do	Division No. 4	1901	.....do	1.88
Bear River Canal	Lateral A 15	1901	Utah	1.84
Average				3.83

These measurements can hardly be considered as representative, since only six canals are represented. They show, however, a decrease in the average quantity of water supplied for each acre of a little more than 11 per cent, compared with the average for main canals as given above. If the averages given for the laterals in this table are compared with those for the main canals from which they are taken, the following results are obtained:

Comparison of quantities of water furnished by main canals and laterals therefrom.

Canal.	Average for canal.	Average for laterals from same.
	Acre-feet per acre.	*Acre-feet per acre.*
Pioneer Canal	8.01	1.41
Amity Canal	4.92	1.82
Lake Canal	2.58	3.11
Pecos Canal	7.90	3.69
Bear River Canal	4.84	1.84
Average	5.65	2.37

Assuming that the laterals given fairly represent all those from the canals named, only 42 per cent of the water entering these canals reaches the laterals. The figures given for the Lake Canal are abnormal, since the lateral shows a greater quantity delivered per acre than does the main canal. There is probably some local cause for this. It is not likely that the others can be considered as representative of canals generally, but they show the conditions on the canals named.

FARMS.

The measurements of the quantities of water used on individual farms are brought together in the following table:

Quantity of water used per acre on individual farms.

State.	Farm.	Crop.	Water used per acre.
			Acre-feet.
Arizona	Vance	Alfalfa and barley	1.98
Do	Arizona Experiment Station	Mixed	5.70
California	Measured to all consumers under Pioneer Ditch.	...do	3.19
Do	Sprott orchard	Oranges and lemons.	1.55
Do	Selected farms under Pioneer Ditch	Fruits	2.00
Do	Pumped water—average for four years on 25 farms—Lindsay Water Development Company.	...do	1.32
Idaho	A. F. Long, 1889	Mixed	2.40
Do	A. F. Long, 1900	...do	3.03
Do	Edgar Wilson	Orchard	1.48
Do	C. G. Goodwin, 1900	Mixed	3.25
Do	C. G. Goodwin, 1901	...do	3.32
Do	N. C. Purcell, 1900	Timothy and alfalfa.	2.43
Nebraska	D. W. Daggett	Mixed	2.47
New Mexico	J. J. Hagerman, 1899	...do	15.44
Do	J. J. Hagerman, 1900	...do	9.80
Do	J. J. Hagerman, 1901	...do	12.36
New Mexico	Average of 70 under Northern Canal, N. Mexico	...do	2.49
Utah	Cronquist	...do	2.59
Washington	Maurice Evans	...do	3.58
Do	Lower Rattlesnake ranch	...do	4.60
Do	Upper Rattlesnake ranch	Alfalfa	3.11
Do	Jordan orchard	Orchard	6.03
Do	Dunn hopyard	Hops	3.43
Do	R. D. Young	Mixed	10.61
Wyoming	Sigman's ranch	...do	3.38
Do	Webber's ranch	...do	1.92
California Gage Canal	N. P. Cayley	Oranges	1.98
Do	J. D. Carscaden	...do	1.20
Do	Gulick Brothers	...do	2.38
Do	C. C. Quinn	...do	1.98
Do	C. E. Kennedy	...do	2.48
Average			3.98

Mr. Reed explains that the water used on the Hagerman farm in New Mexico is used largely for ornamentation, and should not, therefore, be included in the averages. Excluding these, the average for farms is 3.07 acre-feet per acre. This is about 69 per cent of the average quantity diverted per acre, showing a loss of 31 per cent between the heads of canals and the place of use, on the assumption that the measurements are representative, showing a possible source for expansion by saving the losses.

These measurements differ so widely, even where conditions are apparently uniform, that they serve to emphasize what has been already mentioned—the possibility of future development by exercising economy in the use of water.

DEPTH OF WATER APPLIED TO DIFFERENT CROPS.

A large number of measurements of the depth of water applied to different crops have been made in the three years that the work has been carried on. These measurements are given in the following table:

Depths of water applied to different crops.

Crop.	Number of measurements.	Depth of water applied. Maximum.	Minimum.	Average.
		Feet.	*Feet.*	*Feet.*
Alfalfa:				
Idaho	4	3.93	2.04	3.12
Montana	1			1.30
Nevada	1			6.55
Utah	2	3.83	3.19	3.51
Washington	1			3.11
Total and average	9	6.55	1.30	3.39
Barley:				
Arizona	1			1.60
Montana	6	1.98	.85	1.41
Wyoming	1			1.90
Total and average	8	1.98	.85	1.49
Corn:				
Arizona	1			2.10
Wyoming	1			.70
Total and average	2	2.10	.70	1.40
Oats:				
Idaho	2	4.01	1.84	2.93
Montana	11	6.00	.57	1.74
Wyoming	2	1.64	1.56	1.60
Utah	6	2.70	.45	1.35
Total and average	21	6.00	.45	1.73
Orchard:				
Arizona	1			1.27
Idaho	3	3.06	1.48	2.11
Montana	2	1.50	1.48	1.49
Utah	1			5.59
Washington	1			6.03
Total and average	8	6.03	1.27	2.76
Peas:				
Arizona	1			2.40
Montana	2	1.10	.35	.73
Total and average	3	2.40	.35	1.28
Potatoes:				
Arizona	4	2.13	2.00	2.10
Nevada	2	8.16	7.43	7.80
Wyoming	1			3.63
Total and average	7	8.16	2.00	3.94

Depths of water applied to different crops—Continued.

Crop.	Number of measurements.	Depth of water applied.		
		Maximum.	Minimum.	Average.
		Feet.	*Feet.*	*Feet.*
Sugar beets:				
Arizona	2	2.50	2.50	2.50
Montana	1			1.46
Total and average	3	2.50	1.46	2.15
Wheat:				
Arizona	6	2.50	2.10	2.17
Montana	3	2.00	.77	1.18
Nevada	2	14.42	8.26	11.34
Utah	8	2.26	.63	1.42
Total and average	19	14.42	.63	2.68
Hops, Washington	1			3.43
New meadow, Idaho	1			3.32
Old meadow, Idaho	1			2.38
Onions, Arizona	1			6.20
Peaches, Arizona	1			3.40
Strawberries, Arizona	1			6.20
Tomatoes, Arizona	1			4.30
Watermelons, Arizona	2	3.30	3.20	3.25

These measurements differ as widely as those given in the preceding tables, but the averages show in a general way the relative quantities of water required by the different crops included in the table. These averages, for the crops which are generally raised, are repeated in the following table, which also gives the season during which the crops named require water. The season is found by taking from all the statements on that subject which have been contained in reports to this Office the first and last dates for each crop. Statements referring to Arizona are omitted because irrigation continues throughout the year in that State, and its seasons are peculiar to itself:

Depth of water required by different crops, and the irrigating season for each.

Crop.	Depth of irrigation.	Irrigating season.
	Feet.	
Potatoes	3.94	May 17 to Sept. 15.
Alfalfa	3.39	Apr. 1 to Sept. 22.
Orchard	2.76	Apr. 15 to Sept. 2.
Wheat	2.68	Apr. 1 to July 26.
Sugar beets	2.15	July 13 to Aug. 17.
Oats	1.73	May 22 to Aug. 20.
Barley	1.49	June 12 to Aug. 1.
Corn	1.40	July 24 to July 29.

The average depth given for wheat is undoubtedly too large, on account of the excessive quantities used in Nevada. The season for sugar beets, as given in the table, refers to Montana alone, and is too short for States farther south. It should be extended at least to September 1. Making these allowances, the table shows that in general the crops requiring the most water have the longest seasons. The

statements made in this table are of value as showing what crops can be raised with a given water supply. The grain crops require the least water, and require it at a season of the year when the streams supply the most. Orchards, potatoes, alfalfa, and sugar beets require water during the season when the flow of streams is at a minimum, and hence only small areas of these crops can be raised without storing water. On the other hand, these crops give much larger returns than the grain crops. The following table gives the average returns per acre for the crops named in the last preceding table. These averages are made from all the returns which have been included in all the reports to this Office.

Crop returns per acre.

Potatoes	$75.44
Orchard	53.77
Sugar beets	42.99
Alfalfa	25.36
Barley	24.82
Wheat	15.95
Corn	15.32
Oats	15.22

Dividing these into two groups, those requiring water late in the season and those not requiring it then, gives average returns of $49.39 per acre for the late crops and $17.83 per acre for the early crops, a difference of $31.46 per acre in favor of the late crops. Grouping the crops in the same way and reducing the figures given for wheat to agree with those given for oats, the late crops require approximately double the depth of water required by the early crops. Leaving out of consideration the cost of land and the labor required on the different crops, a like quantity of water used on 1 acre of late crops will produce a value of $49.39 and used on 2 acres of early crops will bring a return of but $35.66, a balance of $13.73 in favor of using the water for 1 acre of late crops. Against this must be charged the cost of storing the extra water. The portion of water which must be stored will vary with the localities and with the seasons, but 1 acre-foot per acre is certainly a safe estimate. The average cost of reservoirs in the Cache la Poudre Valley, Colorado, as given in a previous bulletin of this Office,[a] is $5 per acre-foot of capacity. The annual maintenance charges are but a few cents per acre-foot, showing a good profit from the late crops, leaving out of account the extra cost for the double area of land required for the grain crops. The above figures show that it is much more profitable to store a part of the flood waters of the early summer for use on late crops than to extend the area of the early crops to the limit of the water supply. In other words,

[a] U. S. Dept. Agr., Office of Experiment Stations Bul. 92.

where the late summer flow of streams is now funy appropriated, but there is an unused flood discharge, storing the flood waters will be more profitable than building canals to bring the flood waters to new land.

INFLUENCE OF WATER-RIGHT CONTRACTS ON DUTY.

Former reports have called attention to the influence of regulations controlling the distribution of water on the quantities used. Mr. Reed's report (p. 48) shows that under the Northern Canal, in the Pecos Valley, New Mexico, those who paid an acreage rate and received all the water they wanted used an average depth of 2.573 feet. Those who paid for the quantity they received used an average depth of 2.026 feet, showing a saving of 0.547 foot, or 21 per cent, as a result of charging for the quantity of water received rather than for the area watered. An agreement has been reached under which the new plan will be followed by all users from this canal, making it possible to increase the area irrigated one-fifth.

Mr. Ross made a series of measurements to test the point here under discussion (see p. 203). The Ridenbaugh Canal, under which these measurements were made, originally made an acreage charge. This was later changed to a charge for the head of water used, flowing continuously throughout the season. In the last two seasons the attempt has been made to change to a basis on which the farmers could pay for the quantity of water received and no more. The new plan is to charge for a 24-hour inch, leaving the farmer to order the water as he needs it, and pay for what he uses. Some trouble has been experienced in adopting the new system, so that water is now disposed of under both plans. The measurements made by Mr. Ross show that those who paid for a continuous flow received water enough to cover their land to a depth of 5.81 feet, while those who received water when they wanted it, and paid for what they got, used enough to cover their land to a depth of 4.14 feet, a saving of 1.67 feet, or nearly 29 per cent. The water supplied by the Boise River is all used, except the flood discharge, so that storage and economy are the only means of a larger agricultural development of the valley. The measurements reported show that an expansion of more than one-fourth can be made by the economy which will be produced by making it to the direct advantage of the farmer to use only so much water as is necessary. This method of increasing the duty of water is, of course, applicable only where water is sold to the farmers. Where rights to water of streams are owned by farmers some other means of limiting the quantities used must be devised. The most effective means, as shown by the report above referred to, is an appeal to self-interest. How this can be accomplished where farmers have rights in the streams rather than in ditches is an unsettled question.

CROP RETURNS.

The following table brings together all the crop returns given in the reports for 1901, where they are expressed in value. The returns per acre-foot are figured on the basis of the measurement of the water used made nearest to the crop. In some cases the measurement is made at the head of a large canal and in others at the margin of the field whose yield is given, so that the results should not be given too much weight. Again, the reports give nothing as to the labor and expense of producing the crop, which is necessary to any estimate of the net return per acre-foot of water, which is the basis of the value of water used in irrigation:

Crop returns, season of 1901.

Crop.	Place.	Returns per acre.	Returns per acre-foot.
Alfalfa	Pioneer Canal, Tule River, Cal	$18.62	$5.84
Do	Pioneer Canal, Tule River, Cal., flume lateral No. 2	19.76	14.00
Do	Pleasant Valley Ditch, Tule River, Cal	8.31	1.32
Do	South Tule Ditch, Tule River, Cal	13.64	1.83
Do	Prosser, Wash., Maurice Evans	50.00	13.37
Do	Prosser, Wash., E. F. Benson	48.00	15.43
Do	Bear River Canal, Utah	25.00	5.17
Do	Lateral A 15, Bear River Canal, Utah	25.00	13.59
Do	Lake Canal, Colo	14.00	5.43
Apples	Pleasant Valley Ditch, Tule River, Cal	25.00	3.96
Beans and corn	do	20.35	3.21
Corn	Arizona Experiment Station	18.00	8.57
Do	South Tule Ditch, Tule River, Cal	17.13	2.30
Deciduous fruit	Pioneer Canal, Tule River, Cal	36.13	11.33
Do	Pioneer Canal, Tule River, Cal., flume lateral No. 2	44.56	31.60
Do	South Tule Ditch, Tule River, Cal	29.97	4.02
Egyptian cotton	Arizona Experiment Station	68.00	13.60
Fruits	Pioneer Canal, Tule River, Cal., 21 selected orchards, chiefly oranges.	157.89	78.96
Garden truck	Pleasant Valley Ditch, Tule River, Cal	33.83	5.36
Do	South Tule Ditch, Tule River, Cal	50.64	6.79
Lemons	Pioneer Canal, Tule River, Cal	52.21	16.37
Do	Pleasant Valley Ditch, Tule River, Cal	71.45	11.32
Do	Sprott orchard	75.00	48.39
Do	South Tule Ditch, Tule River, Cal	48.53	6.51
Melons	Arizona Experiment Station	140.00	42.42
Do	South Tule Ditch, Tule River, Cal	103.64	13.89
Mexican beans	Lake Canal, Colo	17.50	6.78
Mixed	Division 1, Pecos Irrigation Company	16.99	3.33
Do	Division 2, Pecos Irrigation Company	18.42	4.71
Do	Division 3, Pecos Irrigation Company	20.07	6.65
Do	Division 4, Pecos Irrigation Company	13.59	7.23
Nursery stock	South Tule Ditch, Tule River, Cal	917.14	122.94
Oats	Lateral A 15	18.00	9.78
Oranges	Pioneer Canal, Tule River, Cal	137.17	43.00
Do	Pioneer Canal, Tule River, Cal., flume lateral No. 2	125.00	88.65
Do	Pleasant Valley Ditch, Tule River, Cal	62.07	9.85
Do	Sprott orchard	107.14	69.12
Do	South Tule Ditch, Tule River, Cal	111.15	14.90
Potatoes	Prosser, Wash., Maurice Evans	134.40	35.94
Do	Arizona Experiment Station	78.23	37.30
Strawberries	do	500.00	80.65
Sugar beets	Lake Canal, Colo	60.75	23.55
Tomatoes	Arizona Experiment Station	225.00	52.32
Vegetables	Pioneer Canal, Tule River, Cal	20.47	6.42
Do	Pioneer Canal, Tule River, Cal., flume lateral No. 2	15.00	10.64
Wheat	Arizona Experiment Station	21.09	9.46
Do	Lateral A 15	12.80	6.96
Average of all	do	13.53	7.35
Average			21.71

COMPARISON WITH AVERAGES FOR THE UNITED STATES.

There is a growing demand for facts which will enable a farmer in the humid part of the country to compare his present situation with what he may expect in the arid West. The table given below gives the average returns from the leading farm crops for the irrigated West and for the whole United States, the former taken from reports to this Office and the latter from the report of the Twelfth Census:

Comparison of crop returns from irrigation with the averages for the United States.

Crop.	Yield per acre.		Returns per acre.	
	Irrigated.	United States.	Irrigated.	United States.
	Tons.	*Tons.*		
Alfalfa	4.58	2.5	$25.36	....
	Bushels.	*Bushels.*		
Barley	52.51	26.8	24.82	$9.31
Corn	82.75	28.1	15.32	8.78
Oats	47.56	31.9	15.22	7.35
Potatoes	214.76	93.0	75.44	33.48
Wheat	28.87	12.5	15.95	7.03
Average	....	....	28.69	13.18

The advantage in favor of irrigation is $15.51 per acre. From this must be deducted the cost of irrigation. It will usually be necessary to buy a water right rather than build a ditch. The average price for water rights, made up from a large number of reports to this Office, is about $11.50 per acre, varying between $4 and $20. The average annual assessments for maintenance and operation of canals, made up in the same way, is $1.75 per acre. The first cost of preparing land for irrigation is variously stated, ranging from $15 to $12.50 per acre, giving an average of $8.75. The outlay at the beginning is, therefore, about $21.25 per acre, outside of the price of land. Adding 10 per cent of this sum to the annual charge of $1.75, gives an average cost of water of $3.88 per acre per annum, leaving $11.63 per acre as the net advantage in favor of irrigation. Farming under irrigation requires more work than farming in humid regions, but no estimate of the increased cost of raising crops on account of extra labor can be made. This extra cost would reduce the profit from irrigation to some extent, but not a great deal.

The averages given do not represent in either case the results from the best culture. A study of the reports will show much larger returns than those given in the table, while the census averages are far below the ordinary yields from good farming in the humid parts of the country. However, the averages given probably show quite fairly the relative advantages of farming in the two sections.

LOSSES OF WATER.

The variation in the quantities of water lost from different canals and from different sections of the same canals is so great that few generalizations can be made. The measurements on each canal are valuable to its owners, showing them how much is lost. In this way owners can estimate how much they can afford to spend in improving their canals, and can tell where to do the work. Because the interest in these measurements is local few details are included in the summary which follows. These are given, however, in the several reports. Where more than one measurement is given for a ditch, they were made on different dates.

Losses from canals from seepage and evaporation.

Name of canal.	Volume carried.	Loss per mile.	Percentage of loss per mile.	Date.
	Cubic feet per second.	*Cubic feet per second.*	*Per cent.*	
Arizona:				
Arizona Canal	79.90	0.70	0.88	June 26, 1900.
Do	93.25	.75	.80	Aug. 4, 1900.
Do	113.00	.54	.48	Oct. 8, 1900.
Consolidated Canal	124.60	.88	.70	May 29, 1900.
Do	22.80	.50	2.20	June 26, 1900.
Do	53.25	.70	1.31	Aug. 4, 1900.
California:				
Callison Slough	55.00	....	5.20	June 6, 1901.
Tipton Irrigation District	75.50	....	6.80	May 28, 1901.
Do	48.70	....	6.75	June 17, 1901.
Fine Ditch	21.20	....	11.33	May 24, 1901.
Do	31.90	....	16.00	June 18, 1901.
Vandalia Ditch	16.00	....	46.00	Do.
Do	16.00	....	44.50	June 21, 1901.
Do	10.20	....	64.00	July 1, 1901.
Porter Slough	97.60	....	.80	June 1, 1901.
Do	3.70	....	11.50	July 9, 1901.
Poplar Ditch	35.30	....	6.25	June 12, 1901.
Do	73.30	....	3.25	June 14, 1901.
Do	73.30	....	2.84	Do.
Do	42.80	....	9.50	June 27, 1901.
Do	26.90	....	6.55	June 29, 1901.
Do	21.90	....	7.66	Do.
Plano Ditch	7.50	....	16.00	July 1, 1901.
Pioneer Canal	45.00	....	2.14	May 20, 1901.
Do	37.70	....	.46	May 31, 1901.
Do	27.70	....	1.45	Do.
Do	37.20	....	2.20	July 10, 1901.
Do	23.90	....	1.09	Do.
Pleasant Valley Ditch	5.60	....	11.11	July 2, 1901.
Do	4.90	....	8.60	Aug. 1, 1901.
South Tule Ditch	7.90	....	2.80	July 3, 1901.
Do	5.60	....	2.50	Aug. 4, 1901.
Colorado:				
Grand Valley Canal, high line[a]	139.62	.53	.38	July 10-12, 1901.
Lake Canal	456.33	2.23	.49	June 9, 1901.
Montana:				
Middle Creek Canal	98.90	5.38	5.34	July 10, 1899.
West Gallatin Canal	114.45	.98	.86	July 18-20, 1900.
Farmers' Canal	133.10	2.19	1.65	July 30, 1900.
Middle Creek Canal	63.04	1.16	1.84	June 27-28, 1900.
Big Ditch	254.47	2.96	1.16	Aug. 9-13, 1900.
Republican Canal	120.49	3.05	2.53	July 21-24, 1900.
Nebraska: Culbertson Canal	80.62	1.94	2.41	Aug. 7-8, 1894.
Utah:				
Logan and Richmond Canal	82.10	....	2.28	Average of 6.
Logan, Hyde Park and Smithfield	50.57	....	2.65	Average of 8.
Bear River Canal	279.34	4.02	1.44	June 25, 1901.
West Line	138.59	.42	.30	June 25-26, 1901.
Corinne Line	118.94	.82	.69	June 26-27, 1901.
West Line[b]	319.27	3.54	1.11	Aug. 6-8, 1900.
Wyoming:				
Canal No. 2	89.65	....	1.00	July 9-11, 1900.
Do	36.52	....	.94	Aug. 20-22, 1900.
Average			6.75	

[a] Main line of Grand Valley Canal shows a gain.
[b] Includes what is given as main line and west line in measurement of 1901.

The California canals given in the above table show excessive losses and were not included in the measurements of the previous year. Omitting them, for the purpose of comparison, gives an average loss of 1.45 per cent per mile, as against 2.47 per cent last year. The measurements this year include more large canals than those reported last year, which accounts for the smaller percentage of loss. This fact is strikingly brought out by grouping the canals given above on the basis of the volume of water carried at the time of measurement. The following table shows the results obtained by such grouping:

Water lost per mile by canals.

	Per cent.
Canals carrying 100 cubic feet per second or more	0.98
Canals carrying between 50 and 100 cubic feet per second	2.67
Canals carrying between 25 and 50 cubic feet per second	5.22
Canals carrying less than 25 cubic feet per second	17.64
Last item, exclusive of Vandalia Ditch	7.48

The last line was added to the table because the losses from the Vandalia Ditch were so much greater than any others given. The table shows the great advantage of carrying all water, so far as possible, in large canals. There are many valleys in which several canals parallel each other for miles, thereby increasing the losses from seepage enormously over what they would be if the water were all carried in one large canal.

EVAPORATION.

Measurements of evaporation are of much less importance than measurements of seepage, because losses from this source are very small in comparison with that from the other and are in a large measure beyond the control of man. The following table gives the losses at various places where records have been kept by agents of this Office:

Evaporation at various points in United States.

Station.	Time.	Depth.
Arizona:		*Inches.*
Experiment station	May 1 to Dec. 3, 1901	49.08
Mesa	May 2 to Nov. 12, 1900	47.41
Do	Oct. 3, 1900, to Oct. 2, 1901	71.88
Do	Year 1892	79.41
Tucson	Year 1893	74.07
Do	Year 1894	79.49
Colorado:		
Holly	June 13 to Sept. 30, 1899	24.15
Grand Junction	May 4 to Nov. 2, 1901	39.32
Rocky Ford	Apr. 14 to Nov. 30, 1901	61.66
Montana, Bozeman	July 6 to Sept. 30, 1899	20.93
Nevada, Reno	May 4 to Oct. 24, 1900	42.25
New Mexico:		
Carlsbad	May 1 to Nov. 11, 1899	54.62
Do	Apr. 1 to Oct. 31, 1900	35.75
Floating tank, Lake McMillan	June 24 to Sept. 30, 1900	21.14
Roswell	July 18 to Oct. 31, 1900	15.56
New Jersey;		
New Brunswick	July 1 to Oct. 31, 1900; Mar. 15 to July 6, 1901	37.61
Vineland	July 24 to Oct. 14, 1900; Apr. 16 to July 9, 1901	28.93
Utah, Corinne	May 18 to Nov. 9, 1901	40.14
Washington:		
Prosser	May 9 to Oct. 29, 1900	24.60
Do	Apr. 22 to Oct. 28, 1901	30.63
Zillah	June 8 to Nov. 2, 1901	27.09
Wyoming, Wheatland:		
Tank on land	June 9 to Oct. 13, 1900	66.40
Tank floating in canal	do	54 45

IRRIGATION IN HUMID SECTIONS.

NEBRASKA.

Most of the observations in Nebraska have been made on the farm of a seed company, so that there is nothing with which to compare the results obtained. The season of 1901 was very dry, so that the corn crop watered by rainfall alone in the vicinity of Columbus, where the observations were made, was a total failure. On irrigated lands a full crop was raised. No statements of the cost of water or the expense of applying it are made, hence exact figures on the profits from the use of water can not be made.

MISSOURI.

The experiments in Missouri were begun so late in the season that no definite results were obtained. There was an increased growth in plants and trees, which is expected to produce a marked effect on the crops of 1902. The experiments are being continued, and the results will be given in future reports.

WISCONSIN.

The report of Professor King (pp. 313–352) gives the results of a series of experiments extending over several years. These experiments, carried on at the Wisconsin Experiment Station, at Madison, show a marked increase in yields of farm crops. The average increase in the yield of clover hay on irrigated land over that from unirrigated land has been 2.5 tons per acre; the average increase in yield of corn has been 26.95 bushels per acre; and potatoes show a gain of 83.9 bushels per acre. The annual cost of irrigation at Madison has been $6.68 per acre, not including any interest on the investment, but including all extra labor. At current prices, this leaves a net profit from irrigation of about $20 per acre on hay, $11 per acre on corn, and $73 per acre on potatoes. The yields obtained from irrigated land are compared with the general averages for the States having a similar climate, as given in the census reports. This comparison is hardly fair. The census averages include the yields under all kinds of farming. Irrigation will be made use of only by the industrious, careful farmer; therefore the yields under irrigation should be compared with yields from the best culture only instead of with the average yields. This would reduce the figures given above, but it is believed that the returns are sufficient to make a good profit on the investment and extra labor, especially with crops having a high acreage value.

The conditions of soil and climate at Madison do not differ from those of the Middle West generally, and the results given by Professor King show that where water can be obtained without too large an outlay irrigation as a part of intensive farming is very profitable.

Another series of experiments was begun by Professor King, for the purpose of testing the effect of irrigation and fertilization on sandy soils, such as are common in large sections of Michigan, Wisconsin, and Minnesota. These lands are poor in plant food, and retain so little moisture that all attempts to farm them have failed. The experiments included the supplying of both manure and water. Manure alone was of little use, as there was not water enough to make the plant food available. Water alone produced good results, but the application of both gave the best results. The cost of irrigation was $6.70 per acre, and the net gain from irrigation was as follows: Potatoes, $30 per acre; corn, $1 per acre; watermelons, $58 per acre; muskmelons, $45 per acre. From these experiments it seems that with special crops irrigation of the sandy lands is profitable, but the increase in yield of corn is not enough to justify the expense of securing a water supply.

These experiments have not covered a long enough period or a wide enough range of crops to justify any conclusions as to the possibility of reclaiming large areas of the barren sandy lands which have been cleared of timber in the States named above.

NEW JERSEY.

The experiments in New Jersey, reported on in former bulletins of this Office,[a] have been continued, and still show good returns from the use of water. The experiments reported in this volume deal with the efficacy of different methods of applying water. Sprinkling produced better results with sweet potatoes, while running the water in furrows proved the better way with onions. Considering the expense, the furrow method is undoubtedly the better way of applying water.

PUMPING WATER FOR IRRIGATION.

This Office has made but few observations on the use of pumps in raising water for irrigation. Bulletin 87 of the Office of Experiment Stations gives the cost of several small irrigation plants in New Jersey. The following table sums up the data there given:

Cost of small pumping plants.

Pump.	Engine.	Cost of plant.	Capacity.
Single-acting force, 6 by 12 inch cylinder.	2.5-horsepower gasoline.	$270.00	30 to 60 gallons per minute.
No. 2 centrifugal	do	390.00	200 gallons per minute; lift, 18 feet.
Do	do	329.00	150 gallons per minute.
Do	do	230.00	170 to 200 gallons per minute.
Bulldozer power pump	do	450.00	30 gallons per minute.
Not stated	do	190.00	130 gallons per minute.

[a] U. S. Dept. Agr., Office of Experiment Stations Buls. 36 and 87.

The costs as given above include in most cases some means of distributing the water to the land, and in all cases a shed or house to inclose the pump and engine. These plants are in New Jersey, where the freight would be very little. This item would be increased in proportion to the distance from the factories. No data covering the cost of operation are given.

The reports of former years and this report have given meager returns from a few pumping plants, showing the cost of raising water. Mr. Code reports the details of tests made by him, and gives as his general conclusion that with wood at $4 per cord water can be lifted 45 feet for $2.50 per acre-foot, and that with power delivered to the pump at $60 per horsepower per annum water can be lifted 45 feet at a cost of $1 per acre-foot. Both these estimates include the cost of attendance and a fair rate of interest on the investment.

Professor King gives the cost of raising water in Wisconsin. At Madison water was raised 26 feet at a cost of $2.64 per acre-foot, using coal which cost $5 per ton. At Stevens Point water was raised 33 feet at a cost of $3.32 per acre-foot, using a gasoline engine, with gasoline at 11.98 cents per gallon.

Professor Chandler gives the cost of an acre-foot of pumped water in the Tule River Valley at from $5 to $7.40, with a lift of 71 feet, and power costing $50 per horsepower per annum.

The following table gives all the data regarding the capacities of various kinds and sizes of pumps which have been included in all the bulletins published by this Office.

Capacity of pumps.

Pump.	Power.	Lift.	Capacity per 24 hours.
		Feet.	*Acre-feet.*
2.5-inch Lawrence centrifugal	5-horsepower gasoline		0.264
5-inch Krogh centrifugal	12-horsepower gasoline	30	1.32
Do	do		.99
5.5 by 8 inch triplex-acting pump	do	125	.594
8-inch centrifugal			8.80
Do			6.60
Do		19	7.26
Do			7.04
Do		14	8.80
Do	18-horsepower engine (burning wood)		4.40
Do		18	7.70
8-inch Krogh		32	6.60
10-inch centrifugal	80-horsepower engine	39	17.60
12-inch centrifugal		23	15.40
16-inch centrifugal	80-horsepower Frick engine	14.5	35.20
18-inch centrifugal			44.00
20-inch centrifugal		15	44.00
Double-cylinder 6-inch pump	4-horsepower gasoline		.396
Triplex pump, 5.5 by 8 inch plungers	5-horsepower gasoline		.594
Compound duplex pumping engine	80-horsepower boiler		132.00
Worthington compound duplex steam pumping engine	do		176.00

A study of the tables giving the quantity of water necessary for various crops and the times when the water is needed will show how much water a pump must furnish for any given crop. The above table, if it were complete, would show how large a pump is necessary to supply the required amount of water.

GENERAL.

The reports as a whole show an increasing interest in the problems of irrigation development on the part of both private parties and the public generally.

Mr. Reed gives (p. 37) the cause of the failure of irrigation enterprises in the past as the inability to get immediate returns upon investments and the conditions which made it impossible for companies building canals to reclaim Government land to share in the increase in value of the land due to the existence of a water supply. The legislature of the Territory of New Mexico has recognized these causes of failure, and has, through the aid of Congress, made provisions which are intended to overcome them. The law passed provides that not to exceed 75 per cent of the returns from the sales or leases of the lands set apart for the purpose of aiding in the construction of irrigation works shall be paid to the companies building the works to reclaim the lands. The causes given by Mr. Reed as hindering development in New Mexico are not peculiar to that Territory, and the results of the experiment outlined in the law referred to will be followed with interest by all who are interested in the development of the West.

Mr. Code's report shows that the people of the Salt River Valley in Arizona are thoroughly aroused over their water supply, and are spending much time and money in an endeavor to find out the best way to relieve the shortage of water in their valley. Committees have been investigating the possible sources of an increased supply, and an effort was made to get a bill through Congress allowing the counties of the Territory to bond themselves for the construction of the works necessary to obtaining the increased supply. An effort was also made to adopt a comprehensive system of water administration for the Territory. These efforts have failed, but Mr. Code is of the opinion that the interest aroused will in time bring good results in the development of the Territory.

The report of Mr. Ross shows the great interest taken in Idaho in an economical use of water. Mr. Ross has for several years devoted the influence of his position as State engineer to the adoption of regulations under which self-interest will bring about an economical use of water. The report of his work in 1901 shows a considerable success along this line and a gradual weakening of the prejudice shown, not

only in Idaho, but throughout the West, against any restriction whatever on the quantity of water used.

The interest taken in all the problems of irrigation, as shown by the reports which follow, is most encouraging. The measurements of the quantities of water used and lost, and the savings made by the adoption of regulations under which farmers pay for the quantity of water they receive, give reason to believe that the present canals and the existing water supply can be made to serve at least double the area now farmed, with a possibility of still further economies and a further development. With the interest which is being taken in irrigation development, the showing of the possibilities of expansion by better construction and economy in use ought to go a long way toward the realization of those possibilities.

REPORTS OF SPECIAL AGENTS AND OBSERVERS.

NEW MEXICO.

IRRIGATION IN NEW MEXICO.

By W. M. Reed, *Special Agent.*

FAILURES IN THE PAST.

For the past few years there has been but little or no advancement along the line of new irrigation works in New Mexico. The principal reason for this is that those of any magnitude constructed in the past have not been financial successes. There are many causes for these failures, and while a great many of the drawbacks could be removed others would still prove to be stumbling blocks in the way of success for new enterprises, owing to existing conditions over which individuals or corporations have no control.

During the greater activity in irrigation enterprises of ten to fifteen years ago, many schemes such as are usually termed "wild cat" were floated, and were necessarily failures. Others with legitimate ends in view came to the same end by mismanagement. A lack of knowledge of cost of construction and maintenance, of the water supply, of the duty of water, and of the kinds of crops adapted to the climate and soil were factors leading to the downfall of these enterprises.

All of the above-mentioned reasons for failures could now be avoided. The experience of both the engineer and farmer have taught the methods and means of avoiding the mistakes of a few years ago. But one of the great reasons for so many failures was a lack of immediate financial returns with which to meet current expenses and interest on bonds. Nearly all managers had calculated that with the completion of the construction work the lands they were to water would all be taken and farmed and a large revenue would be forthcoming from the water rentals. In few, if any, cases were such results realized. Settlers were few, and even these few were inexperienced in farming by irrigation and often made failures, and therefore were unable to pay for the water used.

Many companies advertised extensively and expensively for the pur-

pose of obtaining settlers, and often made contracts under which they were to be compensated from returns from the land. More failures followed, and as a result the companies were unable to meet running expenses, and bankruptcy followed. Many of the enterprises would ultimately have been successes if they could have met the financial strain for a few years.

Capital became discouraged, and for several years nothing was done toward extending irrigation works except of the smaller kind, requiring but little capital.

NEW LAW TO ENCOURAGE RESERVOIR CONSTRUCTION.

In 1898 Congress granted to the Territory 500,000 acres of land for the establishment of permanent water reservoirs for "irrigating purposes," with the provision that not more than 160 acres should be sold to any one person and that no land should be sold for less than $1.25 per acre. The thirty-fourth assembly of New Mexico, which met in 1901, enacted a law providing for the utilization of this grant[a] as follows:

Whenever any person, association, or corporation shall have obtained the right to appropriate and acquire the lawful use and ownership of water sufficient for the permanent cultivation and irrigation, by means of reservoirs, of lands belonging to this Territory which may have been selected for the establishment of permanent water reservoirs for irrigating purposes under the act of Congress aforesaid, and shall satisfy the irrigation commission of their good faith and ability to so construct the same if aided and assisted by a contract for the sale of a portion of said lands so belonging to said Territory for said purpose, then it shall be lawful for the commissioner of public lands, with the approval of said irrigation commission, to contract with such person, association, or corporation, that in the event of the construction of such reservoir or reservoirs whereby sufficient water for the permanent irrigation and cultivation of said lands shall be secured, the Territory will pay to such person, association, or corporation so constructing such reservoir or reservoirs, in aid of such construction, and after the same shall have been constructed and completed to the satisfaction of said irrigation commission, such proportion, not exceeding 75 per cent, as said board may deem advisable of the proceeds of leases and sales of such of said lands granted and located for reservoir purposes as may be rendered capable of permanent irrigation and cultivation by means of such construction or which may be necessary for right of way or occupation for such reservoirs and the structures appurtenant thereto, not exceeding 50,000 acres in all for any one irrigation enterprise, and not exceeding in any case the amount of money actually expended for such construction.

And upon the due completion of said construction, to be evidenced by a certificate to that effect by the irrigation commission, filed and recorded in the office of the commissioner of public lands, in such form and manner and under such regulations as may be prescribed by said commissioner of public lands, the person, association, or corporation so constructing such reservoir shall be entitled to receive from the Territorial treasurer out of the fund appertaining thereto, upon the warrant of the auditor, such agreed proportion of the proceeds of lands as aforesaid, not exceeding 50,000 acres for any one enterprise, as in such contract provided as and when the said proceeds may be realized.

[a] Acts of the legislative assembly, Territory of New Mexico, 1901, sec. 15, chap. 69.

That is, the Territory will contract with parties who build a canal or reservoir, to water a specified tract, not to exceed 50,000 acres of the lands ceded to the Territory, to pay to these parties a percentage of the price which the Territory receives for these lands when sold to settlers in 160-acre tracts.

Under the encouragement of this act about ten associations or corporations have been formed, and within the next year several reservoirs will be under process of construction. One of the first to organize and apply for a contract under this act was the Rio Mimbres Irrigation Company. This company proposes to store the flood waters of the Rio Mimbres, water that is now absolutely wasted, for the Rio Mimbres has no defined or known outlet. After leaving the narrow valley in the east central part of Grant County it opens out on to a broad plain, and even the flood waters are lost by absorption and evaporation before reaching the Mexican border, some 60 miles to the south. The surface flow of this river has long been appropriated, and some of the most fertile and best-cultivated farms in New Mexico lie along this river in its narrow mountain valley. Beneath the alluvial deposit and on top of the bed rock, along this narrow valley, is a stratum of gravel, and it has been learned through numerous tests that a considerable flow is constantly passing off through this gravel. An attempt was made several years ago to bring this underflow to the surface, but owing to faulty methods or, rather, faulty construction, the attempt was practically a failure.

It is also one of the purposes of the Rio Mimbres Irrigation Company to impound and utilize this underflow. At the place selected for its dam, a point about 8 miles northeast from Faywood Station, and where the narrow valley opens out on to the plain, two biuffs on opposite sides of the river make natural abutments for the dam. A wall of masonry will be carried from bed rock and extend as a core up through the dam. Additional stability will be obtained by the use of loose rock, and an earth apron will aid in holding the water. The canal outlet will be a tunnel through the solid rock, and a spillway will be provided at a distance of three-fourths of a mile from the dam. The spillway will have a solid rock bottom and leads into a parallel canyon, conveying the waters safely away from the structure.

IRRIGATION IN PECOS VALLEY.

SEASON OF 1901.

Records of rainfall have been kept at Carlsbad, Roswell, and the Dry Farm; records of evaporation at Carlsbad, McMillan, and Roswell; and records of humidity at Roswell.

The temperature of this year has been about the average for this

section, the rainfall a little below the average, the humidity above the average, and the evaporation below.

The temperature, rainfall, humidity, and evaporation at Roswell were taken by Mr. P. A. Turnbull, voluntary observer, United States Weather Bureau, the evaporation tank being furnished by the Irrigation Investigations, the other instruments by the Weather Bureau.

The evaporation tank is a zinc-lined box, a cube with 3-foot sides, and set in the ground nearly flush with the surface and protected from dogs, birds, etc., by a wire netting.

The results show a relation between humidity and evaporation, but there are not enough records from which to calculate a ratio. The continued high humidity of October culminated on November 1 in the heaviest rainfall that Roswell ever experienced—5.65 inches fell in fourteen hours.

At Lake McMillan, the storage reservoir of the Pecos Irrigation and Improvement Company, a floating tank was used for evaporation tests. The tank is a wooden box, zinc-lined, a cube with 3-foot sides, and was floated by a wooden structure with the top about 6 inches above water level.

The records were not continuous, owing to other duties of the watchman who had charge of the observations, but enough was done to make them interesting when compared with the records of the tank at Carlsbad. McMillan and Carlsbad are only 12 miles apart, and the temperature conditions are about the same.

During the spring when the winds were high the floating tank shows the higher evaporation, but during the summer, with little wind and a higher temperature, the tank at Carlsbad, which is similar in construction to the one at Roswell, and is set in the ground, showed the greater evaporation. From this it is observed that large bodies of water like reservoirs, having much surface exposed to winds, lose more by evaporation during the windy months than smaller bodies, which are more affected by temperature, but do not have the surface exposed to wind action. The following table gives the daily evaporation from the tank floating in Lake McMillan.

Evaporation from floating tank, McMillan, N. Mex., 1901.

Day.	May. Evaporation.	May. Remarks.	June. Evaporation.	June. Remarks.	July. Evaporation.	July. Remarks.	August. Evaporation.	August. Remarks.	September. Evaporation.	September. Remarks.
	Inches.		*Inches.*		*Inches.*		*Inches.*		*Inches.*	
1					0.12	Warm and cloudy	0.00	Showery	0.00	Showery.
2					.12	High wind	.00	Cloudy	.00	Do.
3					.25	Hot and clear	.25	Clear	.00	Do.
4	0.25	High wind			1.00	Hot wind	.25	do	.00	Do.
5	.25	Light breeze			.12	Hot and showery	.25	do	.00	Do.
6	.25	Showery			.13	Showery	.00	Cloudy	.00	Cloudy.
7	.57	do			.25	do	.00	do	.00	Do.
8	.13	Light breeze			.25	Clear	.25	Clear	.00	Do.
9	.12	do			.25	do	.00	Cloudy	.00	Do.
10	.38	do			.25	Hot wind	.00	Showery	.00	Do.
11	.25	Showery			.25	do	.00	do	.00	Do.
12	.25	Light breeze			.00	Cloudy	.00	do	.00	Do.
13	.25	Showery			.00	do	.25	Clear	.25	Clear.
14	.12	Light breeze			.00	Cloudy; some rain	.00	Cloudy	.25	Do.
15	.38	High wind			.25	Hot and clear	.00	do	.25	Do.
16	.25	do			.25	do	.00	do	.25	Do.
17	.25	Light breeze			.50	Very hot	.00	Showery	.00	Cloudy.
18	.25	do			.50	Hot and clear	.00	do	.00	Do.
19	.25	do			.50	do	.00	do	.50	Clear and windy.
20	.25	do			.50	do	.25	Clear	.25	Do.
21	.12	do			.12	Clear	1.00	Very hot	.25	Do.
22	.38	Windy			.00	Showery	.00	Showery	.50	Do.
23	.25	Light breeze			.00	do	.33	Clear	.50	Do.
24	.25	do	1.00	Hot wind	.00	do	.33	do	.50	Do.
25	.12	do	1.00	do	.00	do	.34	do	.25	Do.
26	.13	do	1.00	do	.00	Rained 1 inch	.50	Hot and clear	.25	Clear.
27	.25	do	.50	Cooler; some wind	.00	Cloudy	.50	do	.25	Do.
28	.25	do	.50	do	.00	Rained .50 inch	.50	do	.50	Windy.
29	.25	do	.25	Cloudy	.00	Showery	.50	do	.00	Cloudy.
30	.25	do	.25	Cloudy; strong wind.	.00	do	.50	do	.00	Do.
31					.00	do	.25	Cloudy		
Total	6.70		4.50		5.61		6.28		4.75	

The following table summarizes the results at the three stations above named:

Weather report, Pecos Valley, New Mexico, 1901.

Month.	Roswell.					Carlsbad.				McMillan.
	Temperature.		Humidity.	Rainfall.	Evaporation.	Temperature.		Rainfall.	Evaporation.	Evaporation.
	Maximum.	Minimum.				Maximum.	Minimum.			
	°F.	°F.	P. cent.	Inches.	Inches.	°F.	°F.	Inches.	Inches.	Inches.
April	76	38	....	0.97	....	79.5	42.8	0.93	1.75	....
May	82.7	51.3	....	1.04	....	85.6	58.2	.76	5	6.70
June	93.3	58.3	....	.22	....	96.8	63.8	.60	6.75	[b] 4.50
July	[a] 89.3	64.4	44.8	2.26	2.70	94.8	67.3	1.88	6.50	5.61
August	94.7	63.7	42.1	.60	6.05	95.8	68.5	1.13	7.25	6.28
September	86.2	54.2	43.0	1.97	4.05	87	61.2	.52	4.75	4.75
October	76.8	44.3	60.7	2.21	2.75	76.8	51.3	3.44	3.75	....
Total	....	....	....	9.27	15.55	....	....	9.26	35.75	27.84

[a] July records at Roswell begin with the 18th. [b] June 24 to 30 only.

DUTY OF WATER.

CARLSBAD.

The investigations have been carried on at Carlsbad along the same lines as during the past two years.[a] The policy of the management has been changed but little, except that no restrictions were put upon the quantity of water used by patrons further than that dictated by the carrying capacity of the canal. While the depth of water used this year is slightly more than in former years, many farmers now realize that irrigation means something besides flooding upon every available occasion, and more care is taken to prevent water-logging of their own land and that belonging to their neighbor. However, the process of "subbing" is still going on. It was noticeable this year, and the fact is becoming more apparent each season, that drainage on a large scale will have to be resorted to in order to redeem some lands and protect others. The records given in the following pages, showing the amount of water passing through the canal and that actually supplied upon the land, show a large loss, and this great loss not only reduces the revenues of the company, but is the chief cause of the "subbing." A portion of the water used does not pass through the flume, measurements of which are given below; but, comparing the volume of water passing through the flume with that delivered to lands under the canal below that point, the following results are obtained:

Loss of water from Pecos Canal.

	Acre-feet.
Water passing through the flume from April 1 to November 1	88,400.06
Water used upon land below the flume	32,987.89
Water lost	55,412.17
Per cent of water used	37.3
Per cent of water lost	62.7

[a] U. S. Dept. Agr., Office of Experiment Stations Buls. 86 and 104.

The aquatic growth of moss, weeds, etc., was great this year, and as this was removed but once from the main canal, by drying the canal, and not at all from some of the laterals, the water was carried at a greater depth in canals and laterals, and therefore more surface was exposed both to evaporation and seepage.

Another factor that contributed to this loss was the breaking of the canal at the crossing of Dark Canyon. The canal at this point widens out into a large lake, the bottom of which is loose and coarse gravel. The gravel had been partly covered by deposited silt, and this aided materially in preventing leakage. A large amount of water coming down the canyon, estimated by Mr. Kellough, chief engineer, at 15,000 cubic feet per second, was the cause of breaking the canal and sweeping the silt away, leaving the bottom unprotected. Large amounts of water were lost at this place.

The Hagerman farm.—Measurements of the water used on the Hagerman farm under the Pecos Canal were continued during the season of 1901. The water used on this farm does not vary a great deal from year to year. The place is not farmed for profit. The water is used as much to please the eye as for irrigation, and but for the fact that the soil is almost pure sand and there is quick and easy drainage into the river, with so much water used, the place would be a swamp. The table given below shows the water used on this farm. These measurements were made over a Cippoletti weir with the use of a water register.

Water used on Hagerman farm, near Carlsbad, N. Mex., season of 1901.

Day.	April.	May.	June.	July.	August.	September.	October.
	Acre-feet.	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*
1	6.01	7.71	4.72	8.08	7.16	4.06	4.15
2	5.89	7.53	5.20	6.56	7.10	4.06	3.92
3	6.11	6.76	6.04	3.94	7.49	4.36	3.54
4	5.95	6.01	5.89	7.81	7.14	4.56	3.09
5	5.99	6.47	6.09	....	7.06	3.63	5.11
6	5.89	6.84	5.87	....	6.76	3.22	6.09
7	5.67	7.27	5.79	....	6.91	3.03	5.97
8	5.67	6.97	5.59	2.11	7.12	2.92	7.21
9	5.73	6.99	5.40	5.86	7.37	2.77	5.87
10	5.75	7.16	2.58	6.30	5.16	2.65	5.65
11	4.78	7.01	.51	6.30	4.69	2.66	6.01
12	4.78	6.55	....	6.84	5.61	2.73	5.14
13	1.47	3.88	....	4.17	5.65	2.40	3.42
14	1.23	2.09	....	....	5.28	2.57	2.16
15	2.21	2.19	....	....	5.18	2.12	5.17
16	3.27	4.05	1.25	....	4.97	2.53	5.65
17	5.96	5.30	3.46	3.84	4.17	2.85	5.77
18	7.82	5.63	2.40	6.12	3.64	2.76	5.73
19	8.04	5.65	2.30	5.12	4.81	2.65	5.57
20	8.17	5.44	2.29	5.99	4.91	2.71	6.18
21	8.42	5.29	2.81	6.70	4.57	2.62	6.26
22	8.33	5.32	2.04	5.12	3.96	2.27	6.07
23	8.61	5.32	2.26	4.32	3.80	2.29	6.04
24	8.25	5.77	1.91	4.80	3.75	2.39	5.77
25	6.71	4.05	1	5.10	3.75	2.45	5.87
26	7.01	4.43	....	5.37	3.01	2.66	4.61
27	6.93	3.24	....	6.32	4.28	3.37	3.93
28	7.38	3.61	....	9.02	4.17	4.76	3.63
29	7.36	4.62	....	7.97	4.10	5.73	3.76
30	7.53	4.70	2.87	7.53	3.82	5.84	3.99
31	....	4.69	....	7.36	3.87	....	4.06
Total	182.92	168.54	78.27	147.65	161.26	95.06	155.29

Records were also kept of this weir in the same way as the other records of the system are kept—two measurements each day by the ditch rider. The following shows the different results obtained by the two methods:

	Acre-feet.
By automatic register	988.99
By ditch rider	862.72

The discharge shown by the ditch rider's measurements is 87.3 per cent of that shown by the register.

Duty of water on Hagerman farm, 1901.

Area irrigated ...acres..	80
Water used ...acre-feet..	988.99
Depth of water used in irrigation ...feet..	12.36
Depth of rainfall ...foot..	.77
Total depth of water received by land ...feet..	13.13

The following table gives the duty of water on the Hagerman farm, 1899-1901:

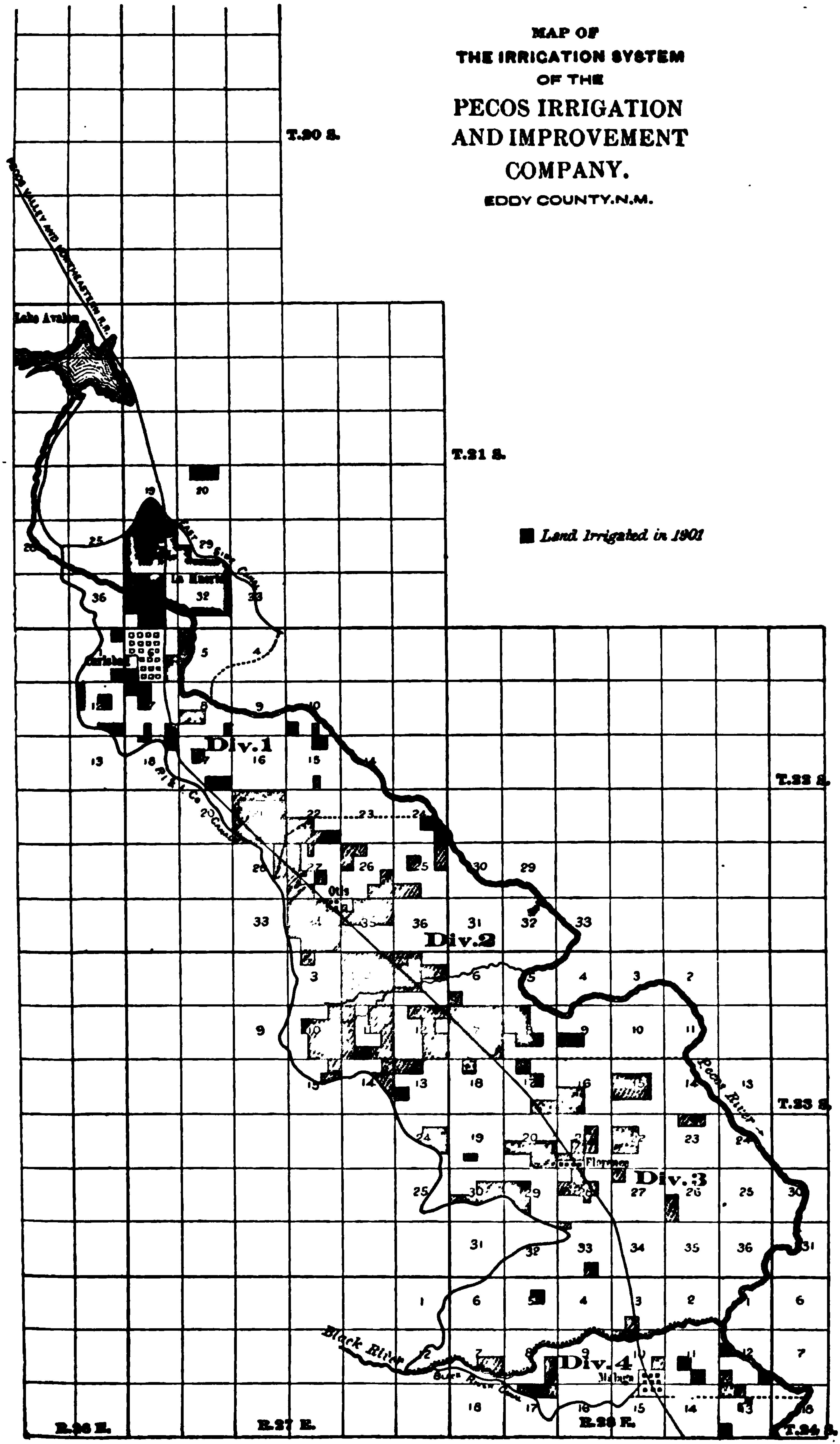
Duty of water on Hagerman farm, 1899-1901.

	1899.	1900.	1901.
Depth of irrigation ...feet..	15.44	9.80	12.36
Depth of rainfall ...foot..	.40	1.00	.77
Total depth of water received by land ...feet..	15.84	10.80	13.13

Pecos Canal.—Very complete records of the results of irrigation under its canal are kept by the Pecos Irrigation and Improvement Company. These records show the areas planted to the various crops, the yields and values of these crops, the water delivered to the farmers, and the time of its delivery. These statements include the Main or Southern Canal, the East Side Canal, and the Black River Canal, all belonging to the Pecos Irrigation and Improvement Company.

The season of 1901 was a very dry one, rainfall at Carlsbad to October 1 being but 9.26 inches, and in the farming district below the town it was even less. However, the water supply was abundant, and there was no shortage at any time. As a result of the dry season much of the wet land has been dried out. Moss in the canals became troublesome very early in the season. It was killed by turning the water out of the canal, no water being run from June 24 to July 2.

The tables showing the use of water in the four divisions (Pl. I) into which the lands under the canal have been divided, give what may be


MAP OF
THE IRRIGATION SYSTEM
OF THE
PECOS IRRIGATION
AND IMPROVEMENT
COMPANY.
EDDY COUNTY, N.M.
Land Irrigated in 1901
T. 20 S.
T. 21 S.
T. 22 S.
T. 23 S.
T. 24 S.
R. 26 E.
R. 27 E.
R. 28 E.
Lake Avalon
Pecos Valley and Northeastern R.R.
Carlsbad
Otis
Florence
Malaga
Div. 1
Div. 2
Div. 3
Div. 4
Pecos River
Black River

termed the net duty of water, as the water is measured where it is used. The following table gives the monthly use of water in each division, taken from the records of the company:

Water delivered during the season of 1901 by the canal of the Pecos Irrigation and Improvement Company.

Division.	March.	April.	May.	June.	July.	August.	September.	October.
	Acre-feet.	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*
No. 1	782.77	1,140.46	1,424.04	1,165.70	1,734.46	1,703.12	908.38	762.13
No. 2	1,559.71	2,273.60	2,964.58	2,325.96	3,177.53	3,062.04	1,664.21	687.66
No. 3	261.43	1,101.24	1,114.48	567.66	1,197.47	1,534.67	398.88	189.83
No. 4	138.38	89.10	289.49	166.25	91.38	103.02	136.95	5.96
Total	2,742.29	4,604.40	5,792.59	4,225.57	6,200.84	6,402.85	3,108.42	1,645.58
Percentages	8	13	17	12	18	18	9	5

Summary of net duty of water for the season of 1901, Pecos Irrigation and Improvement Company.

Items.	Division No. 1.	Division No. 2.	Division No. 3.	Division No. 4.	Total.
Area irrigated ....acres..	1,945.00	4,533.50	2,110.50	542.00	9,131.00
Water used ....acre-feet..	9,941.04	17,714.75	6,365.66	1,020.53	35,041.98
Depth of water used in irrigation ..feet..	5.11	3.91	3.02	1.88	3.84
Depth of rainfall ....foot..	.77	.77	.77	.77	.77
Total depth of water received by land ....feet..	5.88	4.68	3.79	2.65	4.61

The table which follows compares the results in the four divisions for the season of 1901 with those for the two preceding seasons:

Net duty of water, 1899, 1900, and 1901.

Division.	1899.		1900.		1901.	
	Depth of irrigation.	Depth of irrigation and rainfall.	Depth of irrigation.	Depth of irrigation and rainfall.	Depth of irrigation.	Depth of irrigation and rainfall.
	Feet.	*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*
No. 1	6.51	6.94	4.65	5.65	5.11	5.88
No. 2	4.53	4.96	3.39	4.39	3.91	4.68
No. 3	2.95	3.38	2.48	3.48	3.02	3.79
No. 4	3.56	3.99	2.27	3.27	1.88	2.65
Total	3.82	4.25	3.33	4.33	3.84	4.61

Measurements of the water passing through the flume in the main canal across Pecos River have been continued through the season of 1901. The water passing through the flume irrigates 8,760 acres. These measurements give the gross duty of water, and include the loss from the canal from seepage and evaporation. The following

table shows the quantity of water passing through the Pecos flume daily:

Flow of water through Pecos flume, season of 1901.

Day.	April.	May.	June.	July.	August.	September.	October.
	Acre-feet.	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*
1	185.84	271.53	674.80	....	561.19	667.21	433.67
2	180.06	210.90	665.37	99.79	496.80	665.65	435.19
3	179.56	246.43	673.95	492.05	393.72	669.73	434.95
4	179.55	228.68	674.80	457.70	452.36	671.44	436.96
5	181.23	244.38	672.69	446.55	437.07	653.53	446.56
6	170.05	247.38	672.69	426.09	412.78	574.47	442.45
7	162.88	251.30	674.25	417.49	414.90	495.77	439.52
8	163.21	252.01	673.08	579.03	450.94	497.99	335.97
9	163.75	252.81	674.65	579.46	453.82	498.71	231.80
10	163.75	254.32	676.35	580.77	527.39	424.72	224.67
11	163.43	252.25	677.07	574.36	541.38	337.41	238.54
12	164.57	238.89	677.34	569.25	536.13	185.26	249.99
13	161.65	244.97	675.64	478.06	535.62	186.25	248.10
14	170.58	249.08	650.89	583.82	546.28	178.37	245.03
15	228.58	249.43	645.01	600.68	619.60	196.97	232.84
16	230.49	277.67	634.81	603.47	615.55	282.75	184.77
17	250.93	334.92	625.92	602.13	620.95	293.44	164.16
18	273.28	350.56	622.98	608.21	623.78	299.23	146.35
19	276.39	356.35	610.71	610.40	621.76	297.63	130.25
20	207.96	429.03	613.25	612.15	615.92	295.24	131.46
21	275.54	483.54	620.61	616.28	619.04	386.69	131.77
22	275.44	489.15	620.35	612.31	617.96	417.02	131.77
23	272.64	487.93	623.06	611.52	648.45	415.76	131.76
24	274.64	488.42	500.02	612.19	663.44	409.93	131.76
25	277.04	723.78	....	613.54	665.26	412.33	133.91
26	278.97	666.24	....	609.75	665.53	429.63	130.93
27	279.69	673.39	....	618.40	669.88	442.10	144.67
28	284.24	674.24	....	619.07	670.30	442.80	146.07
29	295.41	673.95	....	607.23	671.00	440.22	143.90
30	284.24	640.01	....	622.42	671.28	442.21	141.26
31	....	666.19	....	575.82	530.84	....	132.55
Total	6,605.09	12,109.73	15,530.29	16,639.99	17,570.92	12,610.46	7,333.58

Gross duty of water, Pecos flume, 1901.

Area irrigated	acres	8,760
Water used	acre-feet	88,400.06
Depth of water used in irrigation	feet	10.09
Depth of rainfall	foot	.77
Total depth of water received by land	feet	10.86

The results for the three seasons during which measurements have been made at the Pecos flume are given below for purpose of comparison:

Gross duty of water, Pecos flume, 1899, 1900, and 1901.

Year.	Depth of irrigation.	Depth of irrigation and rainfall.
	Feet.	*Feet.*
1899	6.61	7.01
1900	6.99	7.99
1901	10.09	10.86

Loss of water from the canal.—The great difference between the gross and net duties of water are accounted for by the large losses

from the canal by seepage and evaporation. The loss for the past season is discussed on page 45. The following table gives the percentage of the water passing through the Pecos flume lost in this way for the three seasons 1899 to 1901:

Percentage of loss from Pecos Canal, 1899, 1900, and 1901.

	Per cent.
1899	53.0
1900	57.0
1901	62.7

From the farmer's standpoint, the past season has been very successful. Very few experiments have been undertaken. Crops were planted that were known to be a success in the valley. Good yields was the general condition, and good prices prevailed. The farmers have prospered. They have paid their water rentals, and upon that score the water company is well pleased, but the continued waterlogging of land and the greatly increased loss of water from the canal is at least a shadow of a cloud upon continued prosperity and must cause some anxiety as to the final outcome.

RIO FELIX DISTRICT.

This district was formerly watered by a canal known as the Northern Canal of the Pecos Irrigation and Improvement Company. The canal was sold during the receivership of that company and is now owned Mr. J. J. Hagerman. The water was sold to farmers under the same contracts as those of the Pecos Irrigation and Improvement Company at Carlsbad (a copy of which appeared in report of 1899),[a] the company agreeing for the sum of $1.25 per acre to deliver 1 acre-foot of water per acre. For many years the contract was not adhered to under this system any more closely than at Carlsbad. Water was delivered to customers in such quantities as they demanded. For the past two years Mr. Hagerman has given personal attention to his affairs in this section, and has realized that under the old methods no canal system involving so much money can be a success. Such loose methods are unfair to owner and consumer. During the present season all water delivered has been measured, and farmers have been given to understand that they would have to pay for all the water they used, $1.25 entitling them to 1 acre-foot. For all amounts above this an extra charge of 7 cents per acre-inch was to be made. The farmers naturally objected, and rumors of a suit at law filled the air. But it is now understood that an agreement has been reached between the farmers and Mr. Hagerman, and a new contract to take the place of the old will be entered into. By this contract the farmers will pay the same annual rental and receive 2.5 acre-feet per acre, and in case they use

[a] U. S. Dept. Agr., Office of Experiment Stations Bul. 86.

more will have to pay 5 cents for each acre-inch. This seems to be satisfactory to all parties concerned, and is certainly a triumph for good methods.

The farmer will be conservative in the use of water, will lessen the ruining of land, will grow better crops, and really be more prosperous. On the other hand, Mr. Hagerman, knowing how much water he has, can calculate his income from the same and determine the financial condition of the enterprise. The community will be benefited by having a peaceful, prosperous, and large population.

The agitation brought forth some good results, as the following table will show. The column "regular" indicates those holding contracts and entitled to one acre-foot per acre; "special," those with no contracts, receiving water under special arrangement and paying for the same as consumed, the company being under no obligations in case of shortage of water.

Land in cultivation and amount of water used thereon under Northern Canal, season of 1901.

Name of farmer.	Acreage.	Water used.	Water used per acre.
REGULAR.		*Acre-feet.*	*Acre-feet.*
Amis, W. D	10.0	14.66	1.466
Archibald, F. A	25.0	35.31	1.412
Barron, H. C	10.0	18.47	1.847
Barton, M. S	77.5	85.66	1.105
Balcomb, E. D	20.0	47.18	2.359
Bowman, J	40.0	40.00	1.000
Burr, T	40.0	50.31	1.258
Cazier, J	80.0	124.35	1.554
Calliway, M. L	60.0	120.00	2.000
Collins, D	20.0	40.00	2.000
Coon, W. H	60.0	171.82	2.864
Cowan, M. S	40.0	62.01	1.550
Cowan, H	30.0	40.00	1.333
Corbitt, A	10.0	13.49	1.349
Cowles, J. M	10.0	19.35	1.935
Elford, M. H	40.0	47.58	1.189
Feliz Ranch	800.0	3,775.88	4.719
Gregory, C. A	10.0	21.48	2.148
Hobbie, H. R	50.0	49.64	.993
Harshley, M. E	70.0	87.34	1.248
Hagerman, J. J	200.0	698.34	3.491
Holt, L. W	40.0	42.24	1.056
Do	40.0	52.98	1.324
Ingham, A	80.0	154.75	1.934
Johnson, A	40.0	44.22	1.105
Leonard, R. G	40.0	49.40	1.235
Larson, M	40.0	81.13	2.028
Lard, A	40.0	75.56	1.889
Miller, M. J	40.0	92.69	2.317
Miller, J. M	40.0	84.70	2.117
Macey, A. E	40.0	48.14	1.203
Mills, A. G	120.0	264.56	2.204
Otis, C. A	35.0	63.62	1.817
Russell, A	40.0	82.66	2.066
Randolph, W. F	100.0	134.60	1.346
Rowe, G. A	30.0	47.49	1.583
Rakebrand	100.0	134.60	1.346
Steck, H. M	40.0	82.67	2.067
Tanner, O. R	7.5	5.08	.677
REGULAR—cont'd.		*Acre-feet.*	*Acre-feet.*
Washington, W. E	490.0	1,097.94	2.240
White, C. F	80.0	77.38	.967
White, G. A	40.0	67.63	1.691
Willingham, C. B	40.0	54.64	1.366
	3,265.0	8,401.55	2.573
SPECIAL.			
Amis, W. D	15.0	18.05	1.203
Balcomb, E. D	13.0	21.61	1.662
Burr, T	10.0	20.12	2.012
Cowan, H	37.0	58.60	1.583
D'Arcy, J	5.0	3.12	.624
Elliott, W. W	36.0	36.94	1.025
Elford, M. H	15.0	41.77	2.784
Formwalt, W. W	30.0	61.52	2.051
Formwalt, C. C	40.0	105.54	2.638
Foster, A. J	5.0	6.08	1.216
Hortenstein, J. I	23.0	69.62	8.027
Johnston, Wyatt	5.0	12.88	2.576
Morman, J. L	50.0	40.92	.818
McCutcheon, J	8.0	10.55	1.319
Macey, A. E	2.0	4.33	2.165
Mills, A. A	30.0	85.23	2.841
Miller, A. M	5.0	4.41	.882
P. V. Trust Co	60.0	252.69	4.211
Quigley, O	25.0	40.85	1.634
Quigley, W. H	10.0	10.28	1.028
Renter, B. A	25.0	25.73	1.029
Rowls, C. A	34.0	51.06	1.501
Randolph, W. F	1.0	2.16	2.160
Snead, A. J	3.0	4.87	1.623
Sanford, C. M	2.0	2.32	1.160
Stanford & Langford	35.0	93.13	2.660
Krull, A	28.0	33.93	1.211
	552.0	1,118.31	2.026

The table shows that those paying for the quantity of water they actually received used about 6 inches less water than those paying a stated price and taking what water they wanted.

ROSWELL DISTRICT.

In this district the water is owned by individuals. It is obtained from North and South Spring and Berrendo rivers. Ditches are owned by individuals or associations of individuals, and the water is divided among the owners by means of the time system, each owner having full control of the ditch and use of the water for a certain time, this time being in proportion to the whole time of rotation as the individual's ownership in the ditch is to the whole ditch. The period of rotation varies from eight to twelve days. Scarcely any friction arises among the owners of any ditch where this system is in use; but the ditches as units sometimes have disagreements as to their right, and there is now pending a suit among three of the ditches for the settlement of water rights. This suit will bring all the ditches on this stream into court, and a decision will be made; but it is doubtful, under the conditions prevailing in this Territory, whether a decision of the court can be made that will quiet the title and prevent further trouble. For with no supervising or governing agency, sharp practice in manipulating the water, backed up with good testimony, will constantly cause friction, perhaps new suits at law, and possibly, later, different decisions.

The measurements given in the following tables were obtained by the use of a current meter, and, of course, give the flow in each ditch only on the day upon which the measurement was taken, and as water is quite frequently transferred from one ditch to another for various causes and reasons, the duty of water under each ditch is not absolutely correct, but it is comparative, and the whole amount of water in the ditch was used upon the total acreage given in the table:

Duty of water, Roswell irrigation district, season of 1901.

Stream.	Ditch.	Discharge.	Area irrigated.	Area served per cubic foot per second.
		Cu. ft. per sec.	*Acres.*	*Acres.*
North Spring River	Stone	24.23	970	40.033
Do	Lea Cunningham	10.88	600	55.147
Do	Pierce Cunningham	10.87	520	47.838
Do	Pioneer	9.86	830	84.178
Hondo River	Sol Jacobs	11.29	200	17.714
Do	Northern Canal	120.08	3,736.5	31.117
Berrendo River	Last Chance	8.74	245	28.032
South Spring River	Woodlawn	13.34	735	55.097
Do	Pumpkin Row	14.79	740	50.034
Do	Chisum	19.53	1,600	81.925
Do	Texas	11.46	950	82.897
Do	J. M. Miller	13.04	550	42.177
Total		268.11	11,676.5	43.551

The duty of water under the Northern Canal is low owing to long carriage of water, irrigated land being 25 miles from head of canal.

The table shows what a great difference in results is obtained by dif-

ferent individuals even where the conditions are almost identical, and also shows what may be expected when more uniformity and science are used in irrigation.

DRY FARMING.

A rain gauge was placed last spring at the farm of Mr. G. S. Miller, known as the Dry Farm, and situated about 6 miles northwest from Roswell. Mention of operations at this place was made in the report of 1900. The following table gives the rainfall at this point:

Rainfall at Dry Farm, 1901.

Date.	Inches.	Date.	Inches.
April 28	0.80	September 9	0.30
May 31	.90	September 11	.10
July 14	.30	September 30	.10
July 23	1.50	October 5	.50
July 26	.20	October 21	.50
August 8	.25	October 30	1.10
August 11	.35	October 31	2.70
August 17	.50		
September 7	.70	Total	11.10
September 8	.30		

There are no means of irrigating this place, and farming is done by intensive cultivation, conserving as much of rainfall as possible. Very fair crops of sorghum and corn—Indian and Kafir—have been raised for several years last past. This year the farming operations were nearly a failure. The average amount of rain fell, but it came more frequently, and never until the farming season was over did sufficient rain fall at any one time to give the ground moisture enough to be of any value. Mr. Miller's theory is that had the same amount of water fallen in but three or four rains, he could have conserved it and raised good crops.

ARIZONA.

IRRIGATION INVESTIGATIONS IN THE SALT RIVER VALLEY FOR 1901.

By W. H. CODE,
Chief Engineer Consolidated Canal Company.

INTRODUCTION.

The year 1900 in the Salt River Valley, Arizona, is likely to prove an epoch-making one. It was the driest year ever known in the valley, and created a situation so serious that the citizens were united in an earnest endeavor to solve the all-important problem of increasing the water supply. The steps taken to accomplish this important task will be detailed later.

Previous reports have dealt with the variable nature of our water supply, and the difficulty of arriving at exact results concerning the economic use of water. From October 1, 1899, to October 1, 1900, the entire quantity of water for the cultivated lands of the valley, including rainfall, averaged but 2.26 acre-feet per acre. Notwithstanding the limitations and hardships imposed throughout the year, the experience was not without value, as it necessitated an economy in the application of water to the soil, and curtailed to a considerable extent some extravagant uses, among them the so-called "stock water privilege." Good grain crops were raised with a much smaller amount of water than was generally considered necessary. Mention was made in a previous report of a crop matured on the ranch of Dr. A. J. Chandler where all the water received on the land (aside from 2.59 inches rainfall, 10.5 inches) was that which was applied previous to the sowing of the seed. From this small tract of 17.7 acres 41,200 pounds of barley were obtained, which was at the rate of 2,328 pounds to the acre. This crop was equal to the maximum yield from grain lands on the same ranch for the year 1901, although the condition as regards the water supply were vastly different. The fields which produced these large yields received water to a depth of at least 4 feet

during the grain season of 1901, whereas a depth of 2 feet would have been ample could it have been used according to the needs of the crop, and grain lands throughout the entire valley were liberally irrigated, there being an abundance of water during the months of February, March, April, and May. In many instances the crops were doubtless damaged by excessive irrigation, since there was a considerable disappointment and surprise manifest by a number of farmers over the comparatively small yield obtained considering the favorable conditions which had prevailed. This heavy irrigation of our lands when water is plentiful will probably continue until storage reservoirs are constructed on our rivers to regulate or hold in reserve the flood volumes. The farmer who applies an excess of water to his ground during the flood seasons does it because he feels the necessity of thus creating a small storage reservoir in his soil to be drawn upon during the dry months which he knows will follow. While this system may at times be detrimental to crops, it is on the whole a wise one under present conditions.

RAINFALL AND EVAPORATION.

The rainfall for the season of 1901 at Phoenix, Ariz., is given in the table which follows:

Rainfall at Phoenix, Ariz., October 1, 1900, to September 30, 1901.

Month.	Inches.	Month.	Inches.
1900.		1901—Continued.	
October 1	0.14	July 9	0.04
October 13	.04	July 23	.07
October 14	.04	July 27	.01
November 17	.43	July 29	.19
November 18	.65	July 30	.04
November 19	.65	August 1	.15
		August 3	.39
1901.		August 4	.01
January 25	.40	August 11	.11
January 28	.03	August 12	.26
February 7	.04	August 13	.30
March 8	.14	August 17	.19
March 9	.05	August 29	.32
March 31	.14		
May 14	.02	Total	4.93
May 29	.08		

Observations were continued during the past year to ascertain the evaporation taking place from the surface of the water in a galvanized-iron tank 3 feet in diameter, sunk to a depth of 2 feet in the ground in an open alfalfa field. Measurements were taken every two weeks and the tank subsequently filled up to within 2 inches of the top. A rain gauge was maintained within a few feet of the tank and records of the rainfall kept for the year, allowance being made for the latter in the measurements given below:

Evaporation in Salt River Valley, Arizona, 1901.

Time.	Inches.	Time.	Inches.
October 3—October 17	2	April 17—May 1	3¼
October 17—October 31	2¼	May 1—May 15	3½
October 31—November 14	2½	May 15—May 29	4
November 14—November 28	2	May 29—June 12	4⅜
November 28—December 12	1⅝	June 12—June 26	4¾
December 12—December 26	1¾	June 26—July 10	4¼
December 26—January 9	1¼	July 10—July 24	4¾
January 9—January 23	1⅝	July 24—August 7	4⅜
January 23—February 6	1¼	August 7—August 21	4
February 6—February 20	1	August 21—September 4	3⅞
February 20—March 6	1¼	September 4—September 18	3
March 6—March 20	1⅝	September 18—October 2	2¼
March 20—April 3	2¼		
April 3—April 17	3¼	Total for year	71¾

From June 1 to August 1 the total evaporation amounted to about 20¾ inches, and during the same interval the total amount of water received on the lands of the valley from the Salt and Verde rivers, if spread over the 113,000 acres of irrigated land, would cover the tract to a depth of approximately 4 inches only, or about one-fifth of the depth which was evaporated from a water surface during the period of two months named.

If it were not that the rate of evaporation from a soil surface is much less than from a water surface but little could be accomplished with the available water supply in Arizona during the summer months. At the same time it is evident that inasmuch as maximum evaporation will also take place from the water surface of a flooded field, a considerable loss of water must thus be entailed from the time it is first turned upon the land until it is absorbed.

DUTY OF WATER.

Tables are given below which show the amount of water received by each canal in the Salt River Valley, under the jurisdiction of the water commissioner, from October 1, 1900, to October 1, 1901. The writer, on behalf of the Office of Experiment Stations, has cooperated with Water Commissioner Trott[a] for the past two years in gauging the canals of the valley, receiving in return the semidaily readings of all gauges from which the following tables are calculated. The results are all reduced to acre-feet, and will be of interest if the reader will bear in mind that an acre-foot of water is the quantity required to cover 1 acre of ground to a depth of 1 foot, and that under favorable conditions it is sufficient water for one irrigation of 2 acres of land. Deductions of much importance can be readily drawn from a study of these tables, some of which will be included in a subsequent discussion:

[a] The duties of the water commissioner are to enforce the decrees of the district judge under whose authority the water is distributed, and are fully detailed in U. S. Dept. Agr., Office of Experiment Stations Bul. 104, p. 89.

Flow of water in Arizona Canal, October 1, 1900, to September 30, 1901.

Day.	October.	November.	December.	January.	February.	March.	April.	May.	June.	July.	August.	September.
	Acre-feet.	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*
1	173.11	266.78	510.45	309.72	1,695.27	1,274.03	846.59	1,146.84	480.55	116.58	1,417.59	249.42
2	180.69	269.60	472.91	294.25	1,478.33	1,287.42	810.15	1,054.86	477.12	113.15	1,375.93	227.70
3	180.59	268.21	428.08	283.49	1,374.20	1,268.33	803.21	1,079.16	467.01	107.65	1,443.62	283.01
4	181.83	262.46	414.94	285.02	1,686.59	1,254.44	761.55	1,122.55	446.78	101.00	1,381.14	248.08
5	185.55	256.76	409.98	281.95	1,695.17	1,252.71	732.05	1,117.34	410.03	96.60	1,426.26	185.26
6	166.91	255.32	374.13	297.31	1,686.59	1,254.45	702.55	1,054.86	385.19	90.35	1,434.94	155.80
7	171.87	259.64	352.11	301.92	324.99	1,049.15	745.93	964.61	355.83	83.06	1,332.31	152.04
8	173.11	262.46	347.70	306.55	1,165.93	1,242.30	804.94	867.42	330.19	77.85	1,216.26	147.07
9	168.66	259.64	341.31	301.93	1,273.54	1,365.52	804.94	697.34	303.47	73.79	912.55	152.48
10	163.39	255.32	336.50	325.44	1,113.87	1,374.20	782.38	732.05	281.95	68.83	773.70	154.51
11	174.35	248.18	331.79	320.68	208.12	1,339.49	860.48	732.05	252.10	62.88	825.77	824.43
12	199.78	246.74	331.79	314.33	1,070.63	1,248.99	895.19	721.64	224.83	67.83	1,408.91	886.43
13	216.55	249.62	334.91	308.08	1,565.11	1,200.64	848.33	716.43	212.28	58.91	1,412.38	337.04
14	301.29	246.74	333.37	297.31	1,426.26	1,211.06	832.71	692.13	187.83	54.94	1,353.37	165.81
15	488.53	255.32	331.79	285.02	1,313.45	1,193.70	817.09	652.21	193.78	55.93	1,426.26	170.97
16	789.82	256.76	328.61	280.41	1,009.74	1,200.64	811.88	622.81	188.87	45.02	1,152.05	186.24
17	784.61	265.34	323.85	278.93	1,547.74	1,211.80	898.66	596.93	186.25	59.90	992.37	143.85
18	532.56	614.63	319.09	283.49	1,582.46	1,211.80	1,127.75	564.20	181.09	55.93	749.40	148.37
19	428.38	704.78	315.97	278.88	1,582.46	1,235.35	1,178.08	545.31	177.12	53.95	975.02	161.01
20	364.41	159.87	315.97	282.00	1,530.40	1,246.51	1,152.05	514.56	184.91	55.93	834.44	165.71
21	319.04	722.13	333.32	281.95	1,547.75	1,252.71	1,096.51	507.72	174.64	65.85	673.04	154.76
22	312.89	1,183.79	322.26	283.49	1,339.49	1,204.11	1,040.98	519.72	155.85	63.87	650.48	146.18
23	312.89	1,388.58	317.55	281.95	1,521.72	1,203.12	1,110.40	516.25	156.99	240.55	622.86	146.18
24	282.84	1,426.76	314.38	278.88	1,266.35	1,071.96	1,242.30	497.55	154.51	230.58	560.88	142.66
25	275.40	1,390.31	320.68	359.70	1,244.03	1,023.62	1,270.07	470.38	144.99	210.89	448.46	163.24
26	270.54	1,249.74	322.26	1,131.82	1,330.81	1,027.09	1,301.31	456.89	151.44	490.81	378.65	123.82
27	268.21	1,083.12	320.68	1,556.43	1,304.78	1,027.09	1,332.55	428.33	133.14	453.87	279.07	140.58
28	263.90	895.69	318.64	1,582.46	1,270.07	924.70	1,341.22	440.18	129.02	983.70	230.53	146.43
29	266.78	595.04	301.93	1,634.53	....	818.82	1,336.02	413.31	134.43	1,336.02	249.12	142.06
30	271.04	510.74	301.93	1,712.63	....	813.62	1,259.65	475.48	124.16	1,339.49	246.25	133.34
31	263.90	....	311.21	1,743.62	....	780.64	....	499.24	....	1,460.97	258.05	....
Total	9,133.32	16,340.07	10,740.09	16,764.17	37,155.85	36,070.01	29,547.52	21,420.35	7,386.35	8,375.63	28,441.66	6,034.43

Flow of water in the Maricopa and Salt canals (joint head), October 1, 1900, to September 30, 1901.

Day.	October.	November.	December.	January.	February.	March.	April.	May.	June.	July.	August.	September.
	Acre-feet.	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*
1	78.84	63.07	87.77	69.91	415.04	402.15	112.61	103.64	78.84	58.02	170.33	70.41
2	77.85	64.86	93.72	68.93	495.37	431.10	106.61	103.64	79.83	58.02	137.35	70.41
3	90.35	63.07	89.75	68.93	406.11	388.26	115.54	108.59	77.85	58.02	200.58	70.41
4	69.47	63.07	88.76	68.93	394.21	361.73	112.61	106.61	75.87	58.02	450.75	70.41
5	69.47	63.97	88.76	68.93	172.46	395.45	111.57	120.50	76.86	58.02	138.10	67.93
6	62.03	63.97	84.79	67.93	249.42	317.50	104.63	....	75.87	59.50	97.69	67.93
7	69.47	63.97	81.82	66.94	188.18	278.48	95.70	....	75.87	58.02	82.81	67.93
8	69.47	63.07	79.83	65.95	188.18	207.52	94.71	99.17	77.85	58.02	77.85	67.93
9	65.16	63.97	81.82	64.96	397.19	302.97	95.70	97.69	77.85	58.02	77.85	67.93
10	63.07	63.97	78.84	64.96	194.38	334.01	93.72	89.75	78.84	58.02	87.77	67.93
11	77.85	63.97	77.85	64.96	218.78	409.68	93.72	89.75	77.85	58.02	87.77	72.89
12	72.59	63.97	77.85	64.96	406.11	397.19	93.72	89.75	71.90	58.02	219.67	67.93
13	71.90	63.97	76.86	64.96	361.49	303.22	95.70	90.74	67.93	58.02	495.37	70.42
14	66.64	63.07	74.88	64.96	359.75	233.36	94.71	89.75	67.93	53.06	305.22	74.38
15	85.79	63.07	74.88	64.96	379.34	177.47	91.74	89.75	67.93	55.04	433.64	70.41
16	91.73	63.18	74.88	64.96	344.13	132.40	91.74	89.75	67.93	54.55	248.68	67.93
17	72.45	63.07	74.88	64.96	393.72	140.97	91.74	89.75	67.93	54.05	127.70	67.93
18	66.84	63.07	74.88	64.96	432.89	132.64	89.75	89.75	67.93	52.56	92.73	67.93
19	66.64	344.13	74.88	64.96	513.22	121.49	101.65	89.75	67.93	54.05	102.64	67.93
20	65.75	694.21	74.88	64.96	513.22	127.44	102.64	89.75	67.93	55.04	82.81	67.93
21	66.64	560.33	73.88	68.93	513.22	132.40	100.66	89.75	67.93	52.07	75.37	67.93
22	65.75	396.69	72.89	75.87	540.00	120.50	97.69	89.75	67.93	53.55	77.35	67.93
23	66.84	234.79	72.89	75.87	504.30	117.52	93.72	89.75	67.93	53.06	79.83	67.93
24	64.86	176.03	72.89	74.88	295.04	114.54	93.72	89.75	67.93	52.07	79.83	67.93
25	63.97	137.35	72.89	74.88	557.85	117.52	94.71	79.83	65.45	49.09	77.85	67.93
26	64.86	123.47	72.89	69.91	557.85	119.50	94.71	80.33	62.98	52.07	76.86	62.97
27	64.86	116.53	72.39	444.45	495.38	114.53	101.65	79.83	62.98	51.07	75.37	62.97
28	61.86	111.57	72.89	602.48	397.19	107.60	110.58	78.84	62.98	55.04	72.90	62.97
29	63.07	100 66	72.89	647.11	....	107.60	114.55	78.84	62.98	333.72	74.88	62.97
30	63.07	92.73	72.89	584.63	....	108.60	103.64	79.83	62.98	222.39	74.38	62.97
31	63.07	....	72.89	629.26	....	103.64	....	78.84	....	383.07	70.41	....
Total	2,165.21	4,232.85	2,414.86	4,674.24	10,884.02	6,858.98	2,996.14	2,643.42	2,120.79	2,491.29	4,552.84	2,039.40

Flow of water in Utah Canal, October 1, 1900, to September 30, 1901.

Day	October.	November.	December.	January.	February.	March.	April.	May.	June.	July.	August.	September.
	Acre-feet.	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*
1	40.46	56.53	111.57	75.02	305.45	249.02	151.83	203.70	105.62	28.51	272.08	56.92
2	55.85	55.69	125.11	37.24	411.22	269.15	166.56	239.50	115.89	27.47	263.85	54.39
3	37.39	54.79	94.11	....	376.91	226.56	151.34	267.87	113.36	29.55	360.39	54.79
4	40.01	51.32	89.16	....	246.35	212.48	131.01	287.36	107.86	28.17	314.23	56.53
5	38.53	45.52	90.20	....	224.08	198.05	135.67	208.76	99.17	26.28	297.67	55.24
6	39.27	43.14	92.43	74.08	222.64	197.20	173.45	160 41	90.79	26.19	222.59	53.90
7	38.88	47.16	91.34	73.64	352.07	229.14	208.66	159.62	82.76	24.64	263.30	50.92
8	38.53	51.82	77.06	75.77	378.99	337.83	194.08	108.64	76.76	22.76	152.63	40.46
9	38.53	55.69	80.13	88.66	326.93	368.58	154.11	190.26	70.07	23.35	161.10	40.40
10	38.53	55.49	78.55	90.25	298.66	396.40	250.02	152.13	67.64	21.77	140.18	38.87
11	38.52	54.35	79.59	89.16	341.90	400.46	212.38	161.40	71.55	20.58	143.45	292.41
12	39.27	54.15	79.09	82.26	345.97	419.95	156.79	165.37	70.56	17.95	304.26	103.57
13	41.21	53.55	78.00	75.52	341.90	422.13	171.27	155.36	69.57	17.40	300.64	77.50
14	67.09	55.44	77.50	79.59	254.38	370.66	115.19	148.41	60.16	16.86	289.24	52.21
15	284.38	58.26	76.51	79.09	345.62	408.94	129.02	136.31	56.08	14.43	235.14	41.11
16	178.96	57.82	83.32	75.52	226.56	364.41	185.45	127.09	54.84	13.64	85.19	48.93
17	182.28	61.04	82.21	77.11	221.60	422.13	321.97	118.36	53.95	11.40	14.13	42.74
18	89.11	247.93	81.72	70.56	224.08	369.62	314.48	99.92	53.50	11.16	14.68	39.62
19	81.22	285.12	81.72	70.56	296.78	279.81	235.50	98.93	46.76	11.16	92.13	40.36
20	83.26	178.51	81.72	70.07	315.07	250.46	183.57	118.81	34.41	11.90	99.72	38.87
21	72.55	138.84	80.68	69.07	327.92	238.66	192.15	120.74	40.02	11.16	107.36	35.54
22	73.54	....	81.17	69.57	322.96	235.14	275.26	123.87	40.76	12.64	122.63	34.36
23	70.07	....	80.63	70.07	378.99	229.99	296.68	118.31	37.04	31.54	116.43	27.87
24	68.18	....	81.17	71.06	358.17	245.75	271.09	101.60	40.86	55.73	129.57	28.16
25	66.35	....	80.68	76.01	393.88	251.50	281.90	104.38	38.13	66.64	96.00	26.18
26	60.10	....	81.22	259.44	366.64	211.83	281.80	116.43	31.59	157.88	83.80	30.55
27	60.59	....	80.68	220.86	333.87	225.17	270.94	107.36	32.63	114.11	82.76	33.07
28	53.95	....	79.59	326.93	283.59	185.35	240.25	139.59	29.85	275.60	82.26	30.94
29	50.88	....	78.05	372.74	....	163.88	217.34	109.09	26.88	299.75	67.09	32.97
30	54.45	170.13	76.51	388.56	....	161.90	226.84	135.62	30.94	225.77	56.18	33.32
31	64.81	....	75.02	406.86	....	169.78	....	116.88	....	382.21	58.39	....
Total	2,166.75	1,932.29	2,606.44	3,614.67	8,823.18	8,711.93	6,296.60	4,601.58	1,849.50	2,038.20	5,029.12	1,587.70

Flow of water in Tempe Canal, October 1, 1900, to September 30, 1901.

Day.	October.	November.	December.	January.	February.	March.	April.	May.	June.	July.	August.	September.
	Acre-feet.	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*
1	169.19	242.48	264.30	265.59	740.43	538.76	434.73	336.79	301.68	68.13	616.41	269.45
2	169.19	244.96	284.38	264.30	625.29	497.75	407.45	415.29	292.16	52.76	575.65	257.85
3	170.28	241.29	301.83	263.01	644.23	634.29	397.64	428.13	303.07	50.98	668.53	245.20
4	170.28	241.69	295.04	265.59	582.07	622.71	367.49	432.00	300.29	41.35	585.12	259.13
5	164.83	232.56	272.38	270.89	490.41	640.76	372.64	433.98	288.15	33.32	527.50	228.84
6	167.01	237.52	276.59	261.72	594.50	598.06	380.33	411.47	282.79	29.75	499.44	198.14
7	157.19	189.87	276.59	261.72	671.16	653.80	386.93	393.02	273.42	29.75	654.99	181.09
8	143.40	225.12	273.42	266.88	638.18	753.77	396.50	381.17	270.79	25.20	402.20	169.19
9	143.40	221.40	278.78	264.30	633.22	829.14	414.69	422.53	265.58	26.18	350.18	138.59
10	140.28	221.11	278.78	265.59	636.05	841.19	445.29	422.48	259.14	20.83	351.81	123.58
11	137.16	220.16	278.78	273.42	619.93	816.39	428.08	390.10	256.56	23.21	349.14	411.47
12	140.28	216.59	277.44	270.89	575.81	794.57	396.10	374.88	246.24	15.12	676.16	187.43
13	151.79	222.64	276.10	277.44	555.92	786.64	399.17	371.90	242.48	16.86	675.02	158.28
14	264.30	226.36	277.44	274.76	543.52	782.77	386.88	371.90	222.64	15.12	479.56	186.10
15	362.23	221.45	276.10	263.01	597.52	779.00	389.95	354.05	218.92	17.70	687.87	181.53
16	280.26	226.36	277.44	263.01	587.90	802.71	397.88	351.22	210.25	17.06	609.47	185.65
17	361.59	225.12	274.76	257.85	545.70	555.57	468.45	335.36	213.97	9.92	455.01	207.77
18	281.45	371.16	272.08	264.30	548.43	503.60	478.56	319.79	194.43	9.92	438.15	186.64
19	283.04	805.29	273.42	269.50	658.61	422.82	452.98	308.63	187.24	9.92	533.70	139.54
20	270.74	550.41	283.78	265.39	693.22	477.02	436.76	296.33	180.10	9.92	314.63	126.69
21	264.30	700.31	269.55	264.30	665.80	452.03	432.00	310.02	163.98	9.92	301.79	129.92
22	246.74	434.28	264.30	264.30	701.16	402.15	417.72	314.18	159.42	12.20	297.52	131.95
23	220.41	218.78	269.45	263.01	740.83	433.58	433.79	321.12	153.82	75.42	310.02	117.82
24	245.01	171.57	269.45	261.72	725.35	416.18	459.47	315.57	140.68	122.98	336.00	117.82
25	248.83	128.68	270.74	268.26	699.67	452.08	470.83	291.27	124.61	170.53	260.93	102.15
26	253.98	94.21	268.16	600.89	672.20	463.39	502.26	270.79	117.32	284.53	228.84	112.56
27	257.85	....	265.59	535.98	666.40	395.26	625.54	276.10	105.12	264.55	248.79	111.27
28	264.30	99.17	265.59	609.57	608.48	385.38	616.41	311.70	99.17	468.10	255.27	103.13
29	260.43	263.60	266.88	727.29	....	456.00	415.98	269.45	84.64	550.21	235.04	105.12
30	203.80	269.21	261.72	747.57	....	415.73	351.72	299.00	81.81	498.30	240.05	110.08
31	232.56	....	264.30	742.16	....	433.19	....	308.71	....	656.23	274.86	....
Total	6,826.10	7,963.35	8,505.16	10,614.21	17,611.49	18,036.29	12,963.17	10,838.93	6,240.47	8,635.97	13,439.64	5,182.98

Flow of water in Consolidated Canal (Mesa water), October 1, 1900, to September 30, 1901.

Day.	October.	November.	December.	January.	February.	March.	April.	May.	June.	July.	August.	September.
	Acre-feet.	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*
1	41.06	55.73	119.50	76.86	359.91	100.26	213.87	369.07	117.87	32.83	347.11	65.11
2	35.90	59.60	123.02	107.50	286.31	....	253.29	329.00	114.74	32.63	347.11	59.75
3	33.57	58.51	126.64	108.64	305.95	372.39	242.03	319.64	102.05	27.47	347.11	82.71
4	32.63	60.40	111.57	128.83	355.54	392.23	260.53	319.24	95.90	33.92	347.11	64.11
5	30.64	72.00	108.20	116.58	426.94	375.32	196.86	274.61	108.05	35.75	347.11	52.51
6	28.46	68.63	104.23	80.73	423.47	376.86	179.50	259.44	102.74	30.99	347.11	45.82
7	32.33	68.13	88.61	87.47	356.08	379.83	226.96	234.25	89.55	28.02	247.92	46.61
8	41.36	71.50	94.76	77.25	269.85	396.69	244.16	209.26	90.44	30.25	226.61	49.53
9	40.17	68.88	92.88	78.15	336.50	373.88	188.78	275.40	85.29	30.10	218.83	37.64
10	36.51	64.56	89.40	80.23	331.93	307.73	234.05	264.79	74.88	26.28	206.13	35.11
11	36.30	62.48	91.14	69.02	269.06	379.14	243.32	221.31	54.35	18.19	219.03	248.13
12	38.62	64.56	92.48	70.07	293.85	299.80	250.51	202.07	56.73	20.33	248.92	95.60
13	46.07	64.56	92.08	68.38	328.76	321.62	267.02	189.92	50.97	15.62	227.50	51.47
14	77.06	57.77	94.21	57.57	321.82	316.56	265.19	189.92	46.21	18.10	241.89	58.41
15	259.09	61.19	93.82	60.64	255.27	308.92	244.26	205.79	53.11	17.75	347.11	71.31
16	200.23	70.96	78.59	60.94	272.23	347.70	245.01	200.68	40.66	14.68	259.54	63.86
17	172.26	163.88	74.43	62.88	394.21	359.11	296.93	195.02	36.94	11.40	164.48	87.64
18	141.52	263.50	78.79	62.98	396.69	372.64	280.11	175.83	49.04	9.92	140.08	27.27
19	110.03	320.33	75.77	57.77	396.69	356.43	275.75	138.35	54.74	12.15	356.48	36.64
20	80.13	384.00	80.93	65.45	396.69	351.67	290.43	132.20	43.54	9.92	210.25	42.59
21	62.98	372.99	85.88	76.76	396.69	329.35	300.15	133.14	45.87	15.12	176.73	41.31
22	77.40	304.16	79.83	74.83	396.69	320.33	328.56	141.82	38.73	18.05	180.94	36.39
23	53.01	274.02	66.25	78.05	396.69	300.29	363.32	138.59	44.33	58.96	163.34	37.64
24	72.25	208.36	77.95	71.85	231.67	307.53	356.23	133.09	36.14	54.35	156.59	34.76
25	68.43	205.49	73.39	132.84	341.16	323.20	362.73	121.49	42.69	60.45	130.81	38.67
26	64.86	233.95	79.34	358.56	283.83	327.77	345.17	99.12	30.15	152.33	110.28	49.24
27	60.99	222.45	75.17	248.18	258.40	304.17	343.89	104.23	35.40	110.58	89.16	35.16
28	54.54	202.71	66.94	258.64	258.40	297.92	356.88	95.35	33.22	288.00	62.33	41.41
29	56.93	113.35	67.14	386.03	....	209.55	366.94	83.11	34.91	347.11	59.30	42.25
30	50.38	117.77	75.67	376.61	....	224.18	332.23	129.52	32.92	347.11	64.41	42.94
31	57.72	....	76.46	168.35	....	210.20	....	112.91	....	347.11	68.98	....
Total	2,193.43	4,416.42	2,735.07	3,808.64	9,341.28	9,643.27	8,354.66	5,998.16	1,842.16	2,255.47	6,660.31	1,671.59

Flow of water in the Consolidated East Branch Canal, October 1, 1900, to September 30, 1901.

Day.	January.	February.	March.	April.	July.	August.
	Acre-feet.	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*
1		247.93	49.58			145.14
2		247.93				164.38
3		247.93	247.93			276.84
4		247.93	247.93			186.10
5		247.93	247.93			170.53
6		247.93	247.93			67.09
7		247.93	247.93			81.37
8			247.93			
9		49.59	99.17			
10		49.59	247.93			
11		49.59	247.93			
12		49.59	247.93			101.16
13		148.76	198.39			174.56
14		148.76	198.34			123.97
15		148.76	198.35			53.01
16		247.93	148.76			
17		247.93	148.76			
18		285.12	99.17			
19		298.01	49.58			
20		312.89				
21		298.01				
22		275.21				
23		274.21				
24		247.93				
25		247.93				
26		247.93				
27	247.93	247.93				
28	247.93	247.93		49.59		
29	247.93			59.50	297.32	
30	247.93			59.50	262.36	
31	247.93				379.63	
Total	1,239.65	5,859.11	3,416.47	168.59	939.31	1,544.14

Flow of water in Crismon Ditch, October 1, 1900, to September 30, 1901.

Day.	February.	March.	Day.	February.	March.	Day.	February.	March.
	Acre-feet.	*Acre-feet.*		*Acre-feet.*	*Acre-feet.*		*Acre-feet.*	*Acre-feet.*
1	9.92		12			23	10.91	6.20
2	7.44		13			24	12.41	6.20
3	7.44	12.40	14			25	9.92	
4	7.44	12.40	15			26		
5	7.44	14.87	16			27		
6	7.44	16.11	17			28	1.24	.74
7		12.40	18			29		.74
8			19		7.44	30		.74
9			20		7.44	31		
10			21	7.44	7.44			
11			22	7.44	6.20	Total	96.48	111.32

Flow of water in the Highland Canal, October 1, 1900, to September 30, 1901.

Day.	November.	January.	February.	March.	April.	July.	August.
	Acre-feet.	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*
1			123.97				81.82
2							49.59
3							37.19
4							
5				79.33			
6			49.59	89.26			
7				89.26			12.40
8				89.26			
9				99.17			
10							
11							
12							24.80
13							49.60
14			39.67				39.67
15			49.59	99.17			59.50
16			49.59	99.17			

Flow of water in the Highland Canal, October 1, 1900, to September 30, 1901—Continued.

Day.	November.	January.	February.	March.	April.	July.	August.
	Acre-feet.	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*
17			74.38	89.25			
18			64.46	89.25	14.88		
19	9.92		64.46	89.25	14.88		
20	49.59		89.26		44.63		
21	39.67		89.26		32.23		
22	34.71		99.17				
23			49.59				
34							
25	19.83						
26	16.11						
27	2.48	99.17					
28		123.97					
29	12.40	148.76				74.38	
30		148.76				81.82	
31		148.76				89.26	
Total	184.71	669.42	842.99	912.37	106.62	245.46	354.57

Total flow of water in Salt River canals, October 1, 1900, to September 30, 1901.

Day.	October.	November.	December.	January.	February.	March.	April.	May.	June.	July.	August.	September.
	Acre-feet.	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*
1	502.66	684.59	1,098.59	797.11	3,897.92	2,613.81	1,759.59	2,160.05	1,084.56	304.07	3,060.48	711.31
2	499.39	694.71	1,099.14	772.21	3,551.90	2,485.44	1,744.07	2,142.30	1,079.74	284.03	2,913.86	670.10
3	512.18	685.88	1,040.43	724.07	3,362.78	3,150.15	1,709.75	2,203.39	1,063.34	273.67	3,334.26	686.12
4	494.23	678.94	999.47	748.36	3,470.13	3,103.93	1,633.14	2,267.75	1,026.20	262.46	3,264.45	698.21
5	489.02	670.81	969.52	739.35	2,264.45	3,204.44	1,548.79	2,155.19	982.26	248.97	2,907.17	589.78
6	463.69	668.58	932.18	781.79	3,481.59	3,097.39	1,540.46	1,886.18	937.38	236.78	2,668.86	521.59
7	469.73	628.76	890.48	791.11	2,140.41	2,940.00	1,664.18	1,751.50	877.43	223.49	2,675.11	498.59
8	465.87	673.98	872.78	792.40	2,641.13	3,275.30	1,733.40	1,665.67	846.03	214.17	2,075.55	474.18
9	455.90	669.57	874.91	798.00	3,016.96	3,438.45	1,658.23	1,683.22	802.26	211.44	1,720.51	437.04
10	441.82	660.45	862.07	826.46	2,624.48	3,501.47	1,805.45	1,661.21	762.45	195.73	1,559.59	420.00
11	464.18	649.14	859.14	817.24	1,707.37	3,593.10	1,837.98	1,594.61	712.41	182.88	1,625.16	1,849.33
12	490.56	646.01	858.64	802.51	2,741.45	3,408.44	1,792.31	1,563.70	670.26	179.25	2,983.88	840.96
13	527.50	654.35	857.95	794.38	3,301.93	3,227.65	1,781.49	1,524.35	643.23	166.81	3,335.06	694.71
14	776.38	649.39	857.40	774.20	3,094.16	3,112.76	1,694.68	1,492.12	584.77	158.08	2,832.91	536.93
15	1,480.02	659.30	853.09	752.73	3,089.55	3,165.57	1,672.07	1,438.12	589.82	160.85	3,242.53	535.33
16	1,541.01	674.08	842.83	744.84	2,738.08	3,095.80	1,731.97	1,391.55	562.55	144.95	2,354.93	547.61
17	1,573.19	778.46	830.13	741.72	3,425.29	2,927.60	2,077.74	1,335.42	559.04	146.67	1,753.69	499.93
18	1,111.49	1,590.29	826.56	746.28	3,534.15	2,778.73	2,305.54	1,249.49	545.99	139.49	1,435.04	469.83
19	969.32	2,469.57	821.75	741.67	3,810.25	2,562.17	2,258.83	1,180.96	533.79	141.23	2,059.97	445.48
20	864.30	2,016.59	837.27	747.87	3,850.76	2,460.54	2,210.08	1,151.16	510.89	142.71	1,541.85	441.79
21	785.51	2,534.28	843.32	761.00	3,846.10	2,412.60	2,153.70	1,161.37	492.44	154.12	1,334.29	429.46
22	776.33	2,353.64	820.45	768.05	3,682.11	2,288.43	2,160.20	1,189.34	462.69	160.31	1,328.92	416.81
23	723.22	2,116.17	806.78	768.94	3,877.24	2,290.71	2,297.90	1,184.03	460.11	459.53	1,292.48	396.94
24	733.14	1,982.73	815.85	758.38	3,136.91	2,162.18	2,422.81	1,137.57	440.12	515.66	1,262.87	390.88
25	722.98	1,881.67	818.38	911.70	3,494.48	2,167.93	2,480.23	1,067.36	415.87	557.60	1,014.05	398.17
26	714.35	1,717.49	823.88	2,420.63	3,459.27	2,149.58	2,525.26	1,024.06	393.48	1,137.62	878.43	379.14
27	712.51	1,424.58	815.00	3,353.01	3,306.75	2,066.23	2,674.56	995.85	369.27	994.18	775.15	383.05
28	701.55	1,309.14	803.65	3,751.98	3,066.89	1,901.70	2,714.93	1,065.66	354.24	2,070.44	703.29	384.88
29	698.08	1,085.06	786.89	4,164.40	....	1,756.61	2,510.28	953.80	343.84	3,238.51	685.43	385.37
30	642.74	1,160.58	788.73	4,206.69	....	1,724.77	2,333.60	1,119.45	332.81	2,977.24	681.22	382.65
31	682.06	....	799.88	4,086.94	....	1,697.45	....	1,116.58	....	3,698.48	730.69	....
Total	22,484.91	35,068.79	27,002.14	41,385.02	90,614.49	83,760.98	60,433.22	45,508.01	19,439.27	19,981.42	60,021.68	16,516.12

Duty of water under Salt River canals, 1901.

Canal.	Area irrigated.	Water used.		Loss.	Depth of irrigation.	Depth of irrigation and rainfall.	Duty per cubic foot per second.	Duty per miner's inch.
		Total.	Per acre.					
	Acres.	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*	*Feet.*	*Feet.*	*Acres.*	*Acres.*
Arizona, Maricopa, and Salt (joint head)	60,000	275,482.99	4.59	1.15	3.44	3.85	157.68	3.44
Utah	10,000	49,257.96	4.93	1.23	3.70	4.11	146.95	3.67
Tempe	30,000	121,857.76	4.06	1.02	3.04	3.45	178.24	4.46
Consolidated (Mesa Water)	13,000	58,920.46	4.53	1.14	3.39	3.80	158.81	3.97
All Salt River canals	113,000	522,210.38	4.62	1.15	3.47	3.88	156.70	3.92

An inspection and study of the tables reveals many interesting facts. As an example, a comparison of the table of flow of the Highland and Utah canals will illustrate to one unfamiliar with local conditions in the Salt River Valley the great advantage enjoyed by the Utah Canal as regards its more abundant water supply. This privilege was established by right of the early and beneficial use of water from Salt River by the first settlers under the Utah system. The Highland Canal is what is locally known as a high or flood water ditch, having no right of diversion until there is some 60,000 inches of water in the river. As a consequence, farming under this system is confined almost wholly to grain raising, and this is ordinarily undertaken only when indications are favorable in the fall for a good supply of winter water. This canal received during the entire year only 3,316.14 acre-feet of water, while the Utah Canal diverted 49,257.96 acre-feet during the same period. There is a great abundance of excellent land under the Highland Canal and if the latter had a uniform and constant water supply it could irrigate 10,000 acres of land, or an area equal to that covered by the Utah Canal with the present variable water supply. As it is, the total quantity of water diverted from the river by the Highland Canal during the year included in the table (allowing for loss) would cover an area of 10,000 acres to a depth of but 3 inches, while a similar area under the Utah Canal was covered to a depth of 3.7 feet during the same period.

It is also interesting to study carefully the general duty for the whole valley. On January 30, 1901, the total amount of water diverted from Salt River by all the canals of the valley was 4,206.69 acre-feet, which was the maximum quantity delivered in a single day during the year. This would cover 5,258.4 acres to a depth of 9 inches, or successfully irrigate such a tract in twenty-four hours. Again, on July 18, 1901, the entire quantity of water diverted for the valley land was at the minimum, or only 139.5 acre-feet, sufficient, if handled properly, to furnish a light 6-inch irrigation to about 279 acres in a day.

The table giving the flow of all the canals also shows clearly the great need of a storage reservoir if only to act as a regulator of flow. The total water supply diverted from the river to the valley lands during

00	50,000
00	40,000
00	30,000
0	20,000
00	10,000
A.	
B.	

00	80,000
50	70,000
00	60,000
50	50,000
00	40,000
50	30,000
00	20,000
50	10,000
A.	
B.	

000	80,000
750	70,000
500	60,000
250	50,000
,000	40,000
750	30,000
500	20,000
250	10,000
A.	
B.	

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the year 1901 was 522,210.38 acre-feet, nearly one-half of which amount was applied during the winter months of December, January, February, and March, although the period of greatest need would be more nearly the succeeding months of April, May, June, and July.

An inspection and comparison of the summary following the tables demonstrates that the water is being distributed in a most satisfactory manner. The table giving the flow of the canals on the north side of Salt River shows that the lands under them received sufficient water during the year to cover them to a depth of 3.47 feet, exclusive of rainfall. On the south side, the amount received and distributed by the Tempe, Utah, and Mesa canals was sufficient to cover the irrigated area to a depth of 3.38 feet. Hence there can be no complaint by water users on either side of the river on the grounds of partiality.

The following table brings together the results of all the measurements of the duty of water in the Salt River Valley:

Duty of water in Salt River Valley, Arizona.

Canal.	Depth of water received from irrigation.	Depth of rainfall.	Total depth of water received by land.	Area served by 1 cubic foot per second.[a]
Arizona, Maricopa, and Salt canals (joint head):	*Feet.*	*Feet.*	*Feet.*	*Acres.*
1900	1.96	0.37	2.33	297.00
1901	3.44	.41	3.85	157.68
Utah Canal:				
1900	1.99	.27	2.26	291.00
1901	3.70	.41	4.11	146.95
Tempe Canal:				
1895–96	3.22	.55	3.77	168.52
1896–97	3.31	.94	4.25	166.06
1897–98	3.38	.53	3.91	160.52
1898–99	2.68	.58	3.26	202.80
1900	2.30	.27	2.58	251.00
1901	3.04	.41	3.45	178.24
Mesa Canal:				
1896	4.14	.78	4.92	123.00
1897	3.89	1.04	4.93	130.00
1898	3.51	.57	4.08	145.00
1899[b]	2.86	.40	3.26	....
1900	1.62	.27	1.89	358.00
1901	3.39	.41	3.80	158.81
All Salt River canals:				
1900	1.98	.27	2.25	292.25
1901	3.47	.41	3.88	156.70

[a] The results in this column are computed on the basis of the total flow of the canals, while in the depths given in preceding columns allowance is made for losses from the canals.
[b] Record includes only from January 1 to September 30, 1899, and therefore should not be compared with the others in the table.

CONCLUSIONS CONCERNING THE AVERAGE DUTY OF WATER FOR DIVERSIFIED FARMING.

From the results of the past year's measurements, together with those shown in previous reports covering a period of several years (Pl. II and fig. 1), the writer feels safe in affirming that for the maximum production of crops in the Salt River Valley at least 4 acre-feet of water per acre are required during the twelve months of the year. To insure such a supply on the lands at necessary periods demands storage, and it is

FIG. 1.—Diagram showing yearly and monthly use of water from Salt River, Arizona, from 1896 to 1901.

necessary to calculate upon approximately 5 acre-feet in a constructed reservoir on either the Salt or Verde rivers, owing to the loss from seepage and evaporation in the river channels and canals leading from the reservoirs to the valley lands. It has been stated many times that in event of reservoir construction and a consequent economical delivery of water 2 acre-feet per acre during the year would be sufficient for the requirements of the crops. Such statements are, in the opinion of the writer, exaggerated and misleading.

SUPPLEMENTAL WATER SUPPLY.

PUMPING.

Mention was made in a previous report of the pumping station established during the past year by Mr. S. J. Murphy on the Murphy-McQueen ranch, south of the town of Mesa.

Four 12-inch bored wells were sunk on a line, with 12½ feet centers. The first one was put down 1,305 feet in the hope that an artesian flow might be obtained. As the drill was still in a nonwater-bearing stratum of clay and talc when this depth was reached, it was decided, after having penetrated this stratum 605 feet, to abandon the search for artesian flow and depend upon pumps for raising the water. The remaining three wells, therefore, were drilled to a depth of approximately 212 feet, the formations intercepted being as follows:

Record of wells bored on Murphy-McQueen ranch.

	Feet.
Surface alluvial soil	13
Cemented gravel and bowlders	157
Loose free water gravel, sand, and bowlders	42
Total	212

Below this depth lay another stratum of clay, soft limestone, and chalk rock, 408 feet in thickness.

The pipes were all perforated thoroughly, and a central shaft was sunk to a depth of about 23 feet, which was very close to the normal water level, and from the bottom of this shaft tunnels were run in either direction in order that small sections of the steel well casings might be removed at this level and the wells all connected to one horizontal suction pipe. The four wells were connected by means of a longitudinal suction pipe, from which were suspended the vertical suction pipes leading down in each well to a depth of 25 feet or more below normal water level. The longitudinal pipe was attached to a 12-inch horizontal centrifugal pump having a capacity of 4,000 gallons per minute and located at the bottom of the shaft. The pump was driven by a steam plant, which, in brief, consisted of the following: One boiler, 5 by 16 feet, estimated capacity 80 horsepower; 1 automatic

12 by 16 inch engine, running condensing; 1 brick cement-lined condensing pit, 10 by 22 feet and with a depth of 5 feet, containing 40 2-inch pipes 20 feet in length.

The steam is condensed in the pipes by the water discharged from the centrifugal pump, which passes through the pit previous to its discharge into the irrigating ditches leading to the alfalfa fields. The machinery is all inclosed by a neat brick house, and the entire plant has a substantial appearance. (Pl. III.)

The writer was employed to superintend a test run of the plant after its completion, and through the courtesy of the owners is privileged to embody the following data from the report made to them.

The test run of the plant was begun at 7 a. m. July 4, 1901, and was completed at 7 p. m. July 11, 1901. The intention was to operate continuously for six days, but owing to a twelve hours' enforced stop for repairs to the engine on the 8th, the time was extended to six and one-half days. The average height to which the water was raised during the test was about 44 feet, the discharge pipe being several feet above the ground level. The machinery was run to its maximum economical capacity, and the results obtained were as follows:

Data obtained by test run of pump on Murphy-McQueen ranch.

Number of hours consumed in test	156
Number of hours consumed in stoppages (breaks, oilings, etc)	26.4
Total number of hours operated	129.6
Average number of inches pumped (Arizona measure)	270
Average number of inches pumped (California measure)	338
Total number acre-feet pumped	72.4
Total cords of fuel used	34.75
Daily expense of twenty-four hours' run aside from fuel:	
Two engineers, at $2.25 per diem	$4.50
Two firemen, at $1.50 per diem	3.00
Oil and waste	.75
Estimated cost of repairs and maintenance	1.00
Total	9.25
Total expense of operation during test:	
6½ days, at $9.25 per diem	60.12
34¾ cords of wood, at $3 per cord	104.25
Total	164.37
Cost per acre-foot of water pumped:	
Total cost of pumping	164.37
Acre-feet of water pumped	72.40
Cost per acre-foot	2.27
Expense for each hour actually running:	
Total expense	164.37
Number of hours actually run	129.60
Cost per hour	1.26

MURPHY-MCQUEEN PUMPING PLANT.

The normal level of water previous to the test was 22 feet 6 inches below the average surface of the ground. The water level in each of the wells at the end of the test is shown in fig. 2. The sketch shows that the water in the deep well was not drawn down to within 5 feet or more of the level in the other three wells, which seemed to indicate

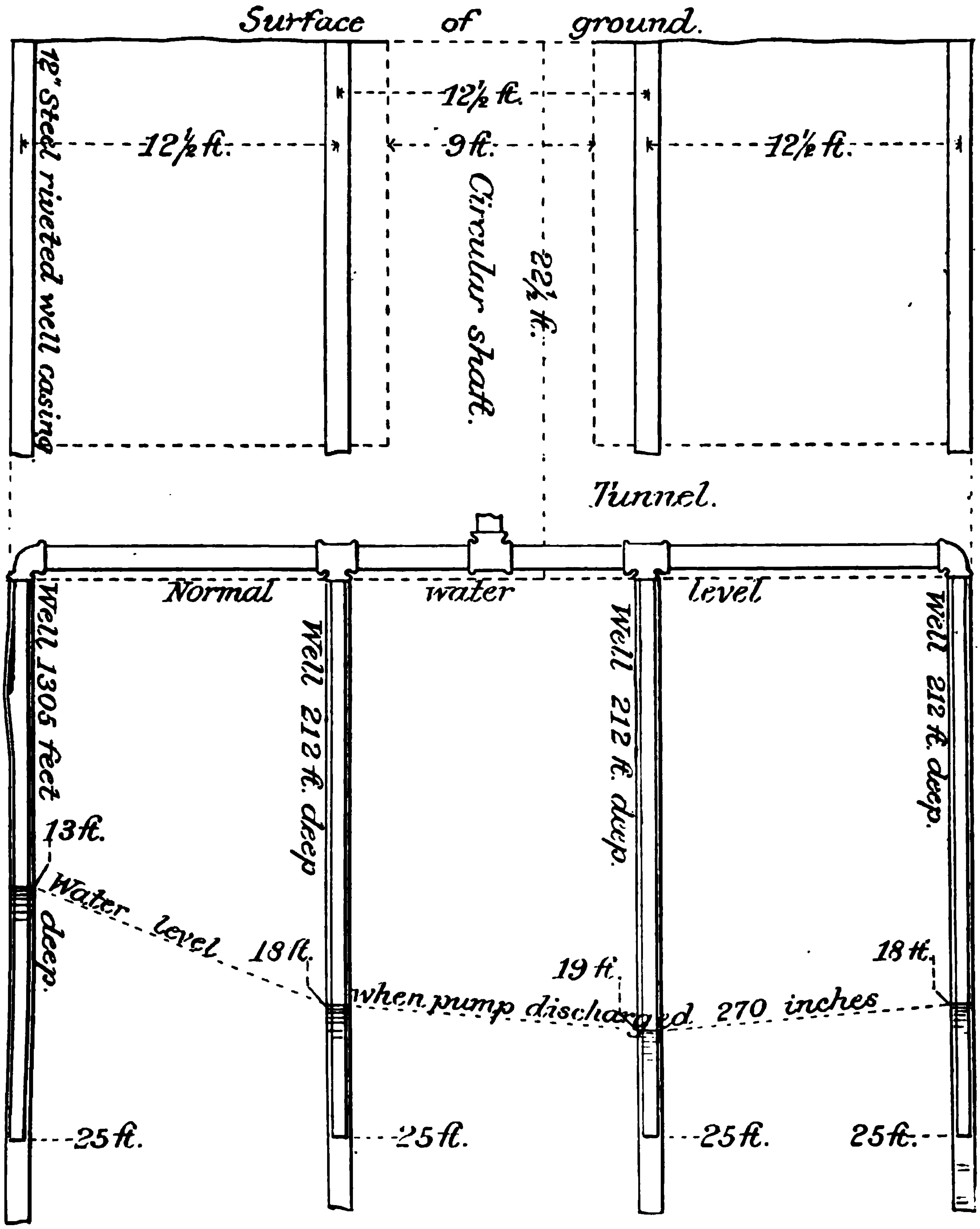

FIG. 2.—Diagrams showing water levels after pumping.

that the well driller was right when he affirmed that it would furnish the greatest supply of water. He based his opinion upon the fact that at a depth of 620 feet, after having penetrated an impervious stratum of clay 408 feet in thickness, a 6-foot gravel stratum was encountered

which caused the water level in the pipes to rise 2 feet above the normal level.

Two samples of pumped water were sent to Prof. R. H. Forbes, of the University of Arizona, at Tucson, to be analyzed for the purpose of ascertaining its value for irrigation purposes. The first was obtained shortly after the pump was started, and the second near the end of the test run, and it will be noted that the analysis of the latter showed considerable decrease of salts, which would warrant the assumption that continued pumping would effect further improvement. In the opinion of Professor Forbes, it would not be wise to depend alone on well water for irrigation purposes, but where it can be used in connection with large quantities of silty river water the danger of depositing an excess of salts on the lands is minimized. The following table gives the results of the analyses made by Professor Forbes:

Analyses of water from McQueen wells.

[Laboratory No. 2615, May 17, 1901.]

	Parts in 100,000.
Total soluble solids, at 110°C	133.20
Chlorin, as NaCl (common salt)	82.00
Hardness, as $CaSO_4$ (sulphate of lime)	11.15
Nitrogen, as nitrates	.426
Nitrogen, as nitrites	.0067

Qualitative tests.—Sulphates, very strong; magnesia, very strong; lime, very strong; bicarbonates, pronounced; silt, small amount.

[Laboratory No. 2670, June 27, 1901.]

	Parts in 100,000.
Total soluble solids, at 110° C	123.20
Chlorin, as NaCl (common salt)	74.60
Hardness, as $CaSO_4$ (sulphate of lime)	9.79
Nitrogen, as nitrates	.263
Nitrogen, as nitrites	Trace.

Qualitative tests.—Sulphates, very strong; magnesia, very strong; lime, very strong; bicarbonates, pronounced; silt, slight traces.

The writer was also anxious to get the opinion of Prof. E. W. Hilgard, of the University of California, on the effect of using water of the composition of that of these wells, and consequently sent to Professor Hilgard the analyses of the water, with a request that he should comment upon its character. I insert the following extracts from the letter received from him:

If used by itself it should be unconditionally condemned on account of its very high content of common salt. If used during four months, to supplement river water, it may be done, but to as small an extent as possible, and in such manner as to diminish evaporation to the utmost possible extent; i. e., for the use in orchards, apply in deep furrows so that the surface will remain dry when the furrow is closed afterwards.

But I am surprised to hear that you are calculating to use 5 acre-feet of water during the season. I do not remember what your rainfall is, but I am satisfied from

our California experience in irrigation, as well as from the list of rainfall, that 3 acre-feet or 30 inches, if properly used, is an abundance anywhere. If you saturate the soil and substrata by winter irrigation you ought not to use more than 1 acre-foot during the season. Even this will introduce 4,125 pounds of salt into the land, three-fifths of which is common salt, which is over the limit of tolerance for citrus fruits, as ascertained by us. If you use 2 feet there will be pretty sure to be damage to such trees, but many deciduous fruits would stand it. Of course, it would not do to allow any such amount of salts to accumulate in the soil during successive seasons. It must be the distinct purpose of the irrigator to use the winter water so as to wash them out into the subdrainage. If the water were used for flooding alfalfa fields to the extent of 2 feet while the plants were young, it would be sure to damage the stand, as in that case the entire amount of the salts would be concentrated near the surface.

Water like this, and worse, has been similarly used as a supplementary supply in South Dakota, but only to the extent of three-fourths inches; the rainfall being sufficient to wash the salts out of the soil into the subdrainage, no injury has resulted.

This letter, from so noted an authority as Professor Hilgard, should be appreciated by the citizens of the Salt River Valley who are contemplating the erection of pumping plants. On the whole, it seems to be the opinion of Professor Hilgard that the secret of success in using pumped water of this character is to subsequently use large quantities of river water to wash out the salts from the soil, and we are fortunately situated in this respect, as during flood seasons there is an abundance of water for this purpose, which is further adapted to the neutralization of the salts by reason of the large quantities of silt which it carries and deposits on the land. Professor Hilgard speaks of our irrigation season, but we have no such distinct season, which in most localities does not average over five or six months. The season in Salt River Valley is for the entire twelve months, and during this time the common practice is to use between 4 and 5 acre-feet of water per acre when it is available. Our efficiency is furthermore lowered, owing to the fact that the greater portion of our lands are used for the growing of products requiring a maximum amount of water for successful irrigation, such as wheat, alfalfa, barley, sorghum, etc. The great degree of heat and consequent increased evaporation makes it impossible to draw any parallel between our conditions in the Salt River Valley, Arizona, and those in California as regards water requirements of crops.

EXPENSE OF PUMPING BY STEAM, AND CROPS WHICH WOULD SEEM TO JUSTIFY IT.

It will be seen that the expense of raising water by steam power is very great indeed, and that as a general proposition such water is too costly for constant use in ordinary farming operations. A plant of this character, however, is valuable as an insurance against drought where the farmers can afford the outlay, and there are numerous times during low stages of the river when a supplemental irrigation of this character would be very valuable, especially in the operation of a stock ranch such as is owned by Messrs. Murphy and McQueen.

They can now calculate with reasonable certainty on carrying a given number of cattle on their section of land, and having ordinarily a large supply of river water, need pump only a portion of the time, during a few months of the year. When the low stages of the river necessitate pumping, water is valuable and feed high, so that they are thus compensated to a considerable degree for the extra outlay involved. With an assured water supply cattle raising should be one of the most profitable industries in the Salt River Valley, for the exceptionally favorable climatic conditions and nutritious feed combine to render it lucrative even under present conditions. (Pl. IV.)

The expense attached to the installation of such a steam plant as the one described, as well as that connected with its permanent operation, will preclude the possibility of a very general use of large plants of this character for common farming operations, but it is not improbable that many smaller plants operated by oil and gasoline may be used ere many years for furnishing a supplemental supply of water on lands which are intensely cultivated and yielding large returns per acre. With a small pumping plant furnishing 60 miner's inches of water for use during the summer season, the horticulturist or gardener would be assured of a crop, and early melon growing would reach a degree of certainty and success now impossible. During the season of 1901 several hundred acres were planted to cantaloupes, but, owing to the lack of water early in the summer, the crop was curtailed in a most disappointing manner. The supply from the river is ordinarily adequate to the needs of the crop until June, and it can be readily seen that the melon grower could pay a good price for a few supplemental irrigations when, with sufficient water, an acre of first-class early cantaloupes will yield gross returns of at least $100. The gardener could well afford to pay $5 for 2 additional acre-feet of water for each acre of his land, which would in all probability be more than sufficient for a crop capable of yielding such returns. The same is true in the growing of Thompson seedless grapes, for frequently the vineyardist finds that his whole year's work is practically lost by the failure to obtain one or two irrigations at critical times in the life of the crop during the spring and early summer. The almond grower and orange orchardist are also confronted to a certain extent by the same danger. Hence, as it has now been demonstrated that the underlying gravel strata of the Salt River Valley contains large quantities of water, it is reasonable to suppose that small pumping plants will be established ere long to draw upon this underground reservoir.

PUMPING BY ELECTRICITY.

The Consolidated Canal Company was the first to attempt the boring of large wells in the Salt River Valley, although, owing to a series of unforeseen delays, its pumping plant was not installed for several months after that of Mr. S. J. Murphy.

CATTLE ON ALFALFA UNDER TEMPE CANAL.

Section of Consolidated Canal Company's well.

	Feet.
Soil and clay	42
Sand stratum	3
Clay and cement	35
Water-bearing bowlders and gravel	156
Total	236

Below the 236-foot level the clay formation was intermixed with small strata of gravel, which continued to the maximum depth reached, of 705 feet. The steel casings were thoroughly perforated throughout the 156 feet of water-bearing strata (gravel and bowlders), and the subsequent supply obtained from them would lead one to think that a subterranean river had been encountered.

A central shaft 9 feet in diameter was sunk to a depth of 31 feet, with tunnels leading to the outside wells, the plan being similar to that adopted at the Murphy-McQueen plant. The three wells were coupled together by means of a horizontal suction pipe, and an 8-inch horizontal Byron Jackson centrifugal pump is used, which, being but temporary, is driven by belt from the 50-horsepower induction motor previously mentioned.

The normal water level in the pipes stands 32 feet below the surface of the ground, and sixteen hours of constant pumping daily has not lowered it over 9 feet to date, although the pump is steadily discharging 4.25 cubic feet of water per second (170 Arizona inches). (Pl. V, figs. 1 and 2.) This amount if furnished steadily is sufficient for the successful irrigation of 640 acres of ground, and is being used at present to seed a half section of land to alfalfa and grain in the immediate vicinity of the station.

Cost of pumping by electricity.—The expense of raising water by electricity varies throughout the West, depending on the necessary expenditure for fuel or the outlay required in the installation of water-power plants. In the Salt River Valley fuel is at a premium, it being necessary to ship in coal and oil from neighboring States, while wood, aside from that on Indian reservations, is nearly exhausted for a distance of 25 miles from the settled portion of the valley. Water power is not easily obtainable, and, as the result of these unfavorable conditions, permanent electrical current can not be cheaply generated. The value of a water-power plant is, as a rule, largely based on the minimum constant supply of water available; hence on a variable river such as the Salt the average summer supply is the one taken into consideration in the designing of the plant. As a consequence, for probably eight months of the year, a much larger amount of power could be developed, which, though of small value for municipal power purposes, could, it would seem, be made of use in developing a supplemental water supply for irrigation by pumping. As a basis of calcu-

lation the value of such power is estimated at $60 per horsepower per annum, delivered at the pumping station.

The efficiency and durability of the pump used is an important factor in the annual outlay required in the maintenance and operation of a plant. The centrifugal pump, while not so economical as others in the market, is generally preferred, owing to its simplicity and lasting qualities, two very important features in a region so remote from a base of supplies.

A San Francisco firm will contract to install the direct-connected plant, and is prepared to guarantee a 60 per cent efficiency in its pumps with the power delivered to the pump shaft, or it will agree to lift 5 cubic feet of water per second (200 inches) a height of 45 feet with 42.5 horsepower.

On this basis of efficiency, with electric current delivered to the station at $60 per horsepower per annum, water could be raised 45 feet at a cost of approximately $1 per acre-foot, which includes the expense of attendance and a fair rate of interest on the money invested in wells, pump, and motor. This would be a reasonable cost for supplemental irrigation during the season, and few farmers would hesitate to pay at such a rate for an extra watering during the early summer and fall, although perhaps they would desire to know what portion of an acre-foot they would be likely to use.

THE AMOUNT OF WATER NECESSARY FOR A SINGLE IRRIGATION.

The amount of water necessary for one thorough irrigation of an acre of alfalfa or grain varies from one-half acre-foot to over one acre-foot, depending on the character of the soil, the slope, condition of borders, uniformity of the ground, distance between head ditches, degree of temperature, and the extent of gopher burrowings. Much also depends on the skill and activity of the irrigator, so that it would be impossible to fix on any arbitrary depth of water as correct for a general standard throughout the valley. Self-recording instruments have been placed in field laterals to determine the amount of water used during single irrigations and the total volume applied throughout the year. Owing, however, to the long dry periods which we have experienced during the past two years, alternating with seasons of floods, the observations have not been satisfactory in determining the depth of water necessary for a single irrigation. The recording instruments have shown that over 2 acre-feet of water per acre was applied to a 60-acre tract in one irrigation during a flood season; but this was extraordinary, owing to the parched condition of the soil and the anxiety of the farmer to use an abundance while the water was available. For the thorough irrigation of alfalfa and grain lands in this valley, three-fourths of an acre-foot per acre can be taken as a fair average under present conditions. For fruit trees or vineyards

FIG. 1.—PUMPING WATER BY ELECTRICITY.

FIG. 2.—WATER-POWER PLANT, CONSOLIDATED CANAL.

where the furrow system is used, a single irrigation rarely exceeds 6 inches in depth.

Since the cost of water from canals in the Salt River Valley ranges from 50 to 80 cents per acre-foot, it will be noted that pumped water at $1 per acre-foot would be a valuable supplemental supply for our lands. In event of reservoir construction by citizens of Maricopa County, they could have not only the additional water impounded to draw upon during the summer months, but the large water power that would be created could be converted into electrical energy, transmitted to the valley, and utilized for the pumping of an additional water supply. Under improved conditions of distribution and a more constant supply it is probable that from 4 to 6 inches in depth would be ample even for alfalfa.

INVESTIGATIONS FOR AN INCREASED WATER SUPPLY.

Mention was made at the beginning of this report of a united effort by the citizens of the Salt River Valley to solve the problem of increasing the water supply. Preliminary steps were taken to secure this by the calling of a mass meeting in Phoenix early in September, 1900, at which 35 representative citizens from all parts of the valley were selected to act as a water-storage committee to consider the question in all its bearings. As the writer was a member of this committee, he is enabled and privileged to give the results of the investigations in this report.

This committee met soon after its organization and divided itself into numerous subcommittees, each of which was to consider carefully and report on some special question connected with the general plan. The questions considered by these special committees were, (1) diversion of the Colorado; (2) diversion of the Gila; (3) underflow; (4) reservoirs and dam sites; (5) silt; (6) available water supply, and (7) pumping. Subsequently a committee was detailed to prepare a bill for Territorial control of the water supply for the consideration of the general committee. In event of its proving satisfactory to the latter it was hoped that the bill would be introduced and passed by the twenty-first legislature. Unfortunately the subcommittee, although faithful in its efforts, was unable to prepare a bill which met with the approval of the entire general committee, and nothing was done toward securing the much-needed legislation.

The water-storage committee met week after week, giving earnest consideration to each of the many schemes submitted.

DIVERSION OF COLORADO RIVER.

Among the plans advanced was diversion of the waters of the Colorado River into the Salt River Valley. It was generally known that the plan was financially impracticable, but it had been the fond hope

of many an Arizona rancher, and a number of them clung tenacious to the idea that at some point in that great gorge there must be a outlet, the location of which would permit the diversion of the wate of this great river whose maximum flow, occurring during the sun mer season, corresponded so well with their period of greatest nee The wish was manifestly the father of the thought in this instanc for subsequent investigations by the subcommittee appointed to repo on the matter revealed its utter impracticability. A letter receive from Mr. W. A. Drake, C. E., who had given the question conside able study, gave some detailed information on the subject, and th following extract from his letter is submitted:

Of course there are several ways of getting the waters of the Colorado River int the Salt River Valley, all being about equally practicable, but none of them presen ing any features that might lead one to believe that the result would justify the cos even though this valley might be transformed thereby into a veritable garden of Ede throughout its whole extent.

The lowest point in the divide between the Colorado River Valley and any tribu tary of the Verde River is about 6,250 feet above sea level. A canal that would carr water over this pass would necessarily have to head in northern Colorado or Wyo ming, and anyone who has seen the Grand Canyon must know what kind of a cana it would be. Imagine a canal several hundred miles in length hanging upon th walls of the Grand Canyon.

The next plan might be a canal heading a little below the same point and leavin the Colorado Valley near Peach Springs, where the dividing ridge has an elevatio of 5,500 feet; thence to the gap at point of red mesa about 2 miles west of Seligman thence down the Chino Canyon to the Verde Valley. Such a canal would cost a few millions less than the first named.

The third plan would be that of building a canal through a gap in the mountains southwest of Congress at an elevation of over 2,000 feet and supporting through a meandering course by way of Big Sandy via Bill Williams Fork, thence to the Colorado River and on up the Colorado River to a point near the junction of the Little Colorado. There would not be over 300 miles of real bad canyon work on this canal.

The above data were sufficient to convince even the most earnest advocate of the plan that his hopes were based on a slight foundation.

DIVERSION OF GILA RIVER.

Another plan suggested was the construction of a canal from the neighboring Gila River and the bringing of a portion of its surplus waters to the lands covered by the Salt River canals. From a preliminary report made by a member of the subcommittee appointed to investigate this plan, the following extracts are submitted:

These surveys show that there are two different canal routes which could be followed for the purpose above outlined. First, one heading at a point about opposite the head of the Florence Canal, which route would bring the canal through at a sufficient elevation to irrigate the lands covered by the Consolidated, Mesa, Utah, Extension, Tempe, and Joint Head canals. This line would necessitate a waterway some 45 miles long, and the cost of same would be very large when it is taken into consideration that the canal would only furnish spasmodic runs of water.

I am not personally familiar with the character of the lands immediately adjoining

SALT RIVER DURING FLOOD OF 1891.

FIG. 1.—CANAL CLIMBING MESA BLUFFS.

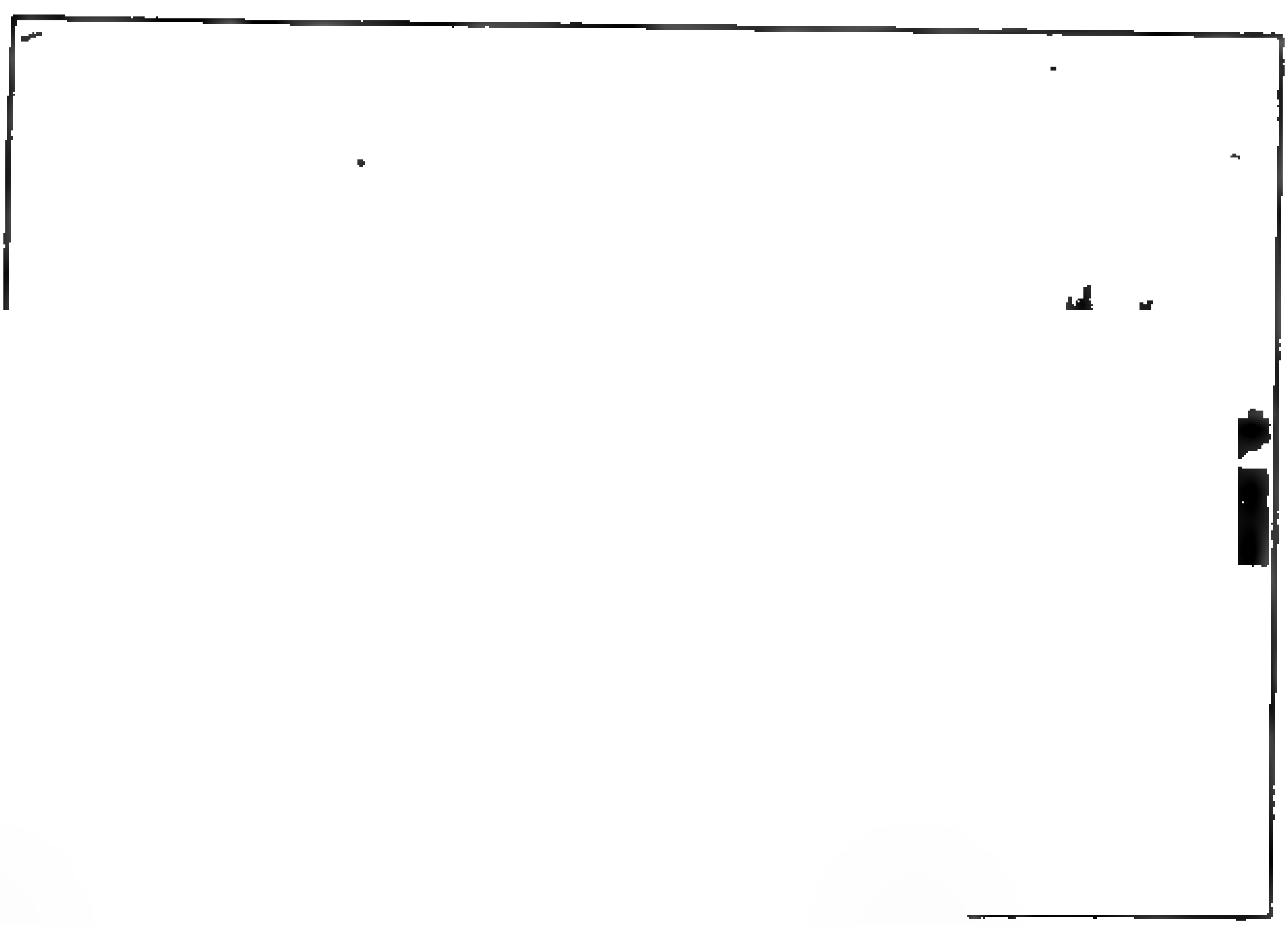

FIG. 2.—A MAIN CANAL IN SALT RIVER VALLEY.

the Gila River, through which we would have to construct the headworks, but have been informed by men who are familiar with the ground that the same difficulties exist, in a measure, which render so expensive the construction of canals from the Salt River to the high mesa lands. With these difficulties the committee is more or less familiar, chief among them being the deep excavation necessary for the first few miles in order to render the canal head safe during flood periods (Pl. VI), and the great expense entailed by the excavation of the cemented gravel in mounting the bluffs along the edge of the mesas. (Pl. VII, fig. 1.)

If such a canal were constructed, it would need to be large, capable of carrying at least 1,250 cubic feet per second (50,000 inches). It should also have a cut of not less than 4 feet in the ground in order that it would not be rendered almost wholly useless by the desert storm waters, which so frequently sweep away canal banks.

A canal of this capacity would need to be 50 feet in width, and with a 4-foot cut, and slopes of 1½ to 1 would cost, including headworks, approximately, as follows:

40 miles of average cross section, 1,752,160 cubic yards, at 10 cents	$175,216
5 miles headworks, at $25,000 per mile, including cost of head-gates, brush-and-rock dam, waste gates, siphons, culverts, etc	125,000
Total	300,216

The next line could be taken out of the Gila River, some 7 miles east of Sacaton, and brought over at a sufficient elevation to irrigate the lands under the Tempe and Joint Head canals. This line would be about 30 miles in length, and cost, approximately, $225,000. These figures simply contemplate a brush-and-rock dam in each instance, and are of necessity approximate, though I have given what is felt to be the minimum cost of either line.

To members of this subcommittee who are familiar with the construction of brush-and-rock dams it will not be necessary to state that it would almost be an impossibility to maintain such a dam sufficiently high to enable it to divert 1,250 cubic feet per second from the Gila River for any length of time. The task would be rendered especially hard by reason of the fact that we will only ordinarily be able to divert such a head of water during and for a short time subsequent to flood periods. In such times the maintenance of a brush-and-rock dam is a trying and most expensive experience. On the whole, the carrying out of either of these plans would prove a costly experiment and should be carefully looked into before investing any funds in the enterprise, notwithstanding our great need of an additional water supply.

UNDERFLOW.

Many of the citizens of the valley believe that if the underflow of the Salt River could be brought to the surface by means of a submerged dam across its channel reaching to bed rock a large volume of water would thus be made available which is otherwise wasted, so far as this valley is concerned.

The subcommittee appointed to investigate this subject immediately put itself in correspondence with many of the leading hydraulic engineers in the West, asking in each instance whether the party addressed had ever known of a submerged dam being constructed which met with the expectations of its projectors. The answers received were, on the whole, disappointing, the consensus of opinion being that throughout the West, outside of perhaps a few instances in California, the

amount of water obtained by the construction of submerged dams was entirely disproportionate to the cost of the works. Mr. J. D. Schuyler, C. E., of Los Angeles, who is more or less familiar with the conditions, estimates that the velocity of the underflow through the sand and gravel of the Salt River will range from 3 to 5 miles per annum. Assuming that a cubic foot of the river sand and gravel contains one-third voids filled with water, and that said water is moving at the rate of even 10 miles per annum, it would take a submerged dam 1,000 feet long and 40 feet deep, founded on impervious bed rock, to develop 45 cubic feet per second (900 inches) of underflow. Mr. Schuyler further states that the construction of a water-tight dam of this character is a most expensive and difficult engineering feat, and strongly advises the construction of surface reservoirs in preference.

RESERVOIRS AND DAM SITES.

Other schemes were presented to the storage committee, but it was soon decided, by the majority, at least, that the most feasible plan for an increased water supply would be the building of storage reservoirs on the Salt and Verde rivers. It is generally thought that the greater portion of the water supply is received from the drainage area of the Salt River proper, but some contend, owing to more frequent summer floods of its tributary, the Verde, that the latter throughout the year furnishes almost, if not quite, as much water as the Salt. In either event it is apparent that, while it would be wiser to construct the initial reservoir on the Salt River, it will ultimately be necessary to follow it with another on the Verde.

It was soon manifest, in the consideration of this question, that there was a dearth of accurate information concerning the depth and character of the bed rock underlying the various dam sites of the Salt and Verde rivers. Soundings had been made with steel rods in some instances, but the results of such investigations are not conclusive in channels whose beds are composed largely of bowlders. Some engineers who have made investigations on our rivers affirm that 60 feet is about the maximum depth to which steel rods can be driven, and that when such a depth has been reached the frictional resistance is so great as to mislead the investigator into the belief that bed rock has been encountered.

As the necessity for accurate information on this point became more and more apparent to the committee, steps were taken by some of the leading members to interest the United States Geological Survey in the matter, first by correspondence and latterly by personal interviews in Washington with the Secretary of the Interior and the chief officers of the Geological Survey. These officials evinced a kindly and active interest in the problem, and promised their cooperation with the citizens of the valley in making the necessary investigations, with

the clear understanding, however, that the storage committee should guarantee a certain proportion of the funds necessary to carry on the proposed work. This was cheerfully assented to by the committee, and the work was soon begun at the McDowell dam site on the Verde River under the able direction of Mr. A. P. Davis, hydrographer. Operations were greatly facilitated by the fact that the necessary Government machinery for making bed-rock borings had been stored temporarily at the San Carlos Reservation in the Territory, subsequent to similar investigations which were carried on by the Geological Survey on the Gila River in 1900.

The main portion of the work on the Verde River, which consisted of bed-rock borings with diamond drills and contour surveys of the reservoir site, was finished early in the summer of 1901. Similar work was commenced immediately on the Salt River at the famous Tonto Reservoir site. This latter work has also been finished, aside from continued observations and studies concerning the flow, quantity of silt, evaporation, rainfall, and extent of drainage area.

The great benefits which would be derived by this valley from the building of a dam on Salt River at the Tonto Reservoir site, seemed, to many members of the committee, to justify its construction, even though the citizens of this county would be thereby plunged into great debt for many years. Without water the beautiful valley would go back to the desert in a very short time, as there are few localities in arid America so absolutely dependent on irrigation. Under such conditions, any plan which promised to improve and increase the water supply was welcomed. Extracts are submitted from a letter written by a very clever attorney, who, although not a resident of the valley, is somewhat familiar with the conditions, and he advocated the following plan of procedure:

(1) That you take immediate steps for the incorporation of a new company, stating in detail and with clearness its objects and purposes, which shall include (*a*) the construction of reservoirs and dams; (*b*) the acquirement of the entire present canal and irrigating system in the Salt River Valley; (*c*) the enlargement and extension of said canals; (*d*) the acquirement of all other facilities and all franchises for water in your valley; (*e*) also the purpose to construct, operate, and maintain an electrical power system.

Of course the above would comprehend a system to supply water throughout the valley for all domestic or other purposes.

(2) Select your incorporators from among your representative men. Only owners of land to be irrigated by this system or to be brought within the system shall be stockholders. Thus these owners of lands and users of water for the purposes of irrigation will control and dominate the company in the selection of its directors and managers.

(3) It may be necessary to secure some legislation at the next session of your general assembly to aid in the accomplishment of the above purposes and to properly guard the interests of the public.

(4) Every owner of an acre of land in your valley is vitally interested in this proposed company for the purposes above stated, and therefore the sole aim should be

to work out the best system and to use the moneys for such company for their exclusive interest, and if they control the stock, as above proposed, they will have in their hands their own interests, and if that interest is injured it will be the result of their own act.

(5) The moment that the organization of the company, as above proposed, is effected it should enter into a contract with Maricopa County, in which contract the county should agree to issue bonds in the amount that the supervisors may determine to aid the construction of the works above proposed upon the terms and conditions to be recited therein, the performance on the part of the county to be made dependent on the passage of a bill in Congress giving it full authority to issue these bonds and to execute such contract and perform the same, provided that the act of Congress receives the approval of a majority of the legal voters of Maricopa County.

(6) County bonds or their proceeds to be exclusively used for new construction work and for the construction of reservoirs and dams. The new company's bonds shall be used (*a*) for the acquirement of the present canals and franchises and (*b*) for security to the county, if any shall be required. The company's bonds shall be strictly limited to the actual cost of the canals and properties so acquired or for the extension and improvement thereof.

It is deemed important to have this contract with the county at the earliest possible moment after the completion of the incorporation and organization of the new company, so as to give confidence to the enterprise and aid in the negotiations for the acquirement of the properties and franchises necessary to the union of all the interests, as above suggested.

This plan appealed to some as one worthy of consideration, but the general opinion was that Maricopa County should not attempt to go to such lengths at this time, but rather confine all its energy primarily to the construction of storage reservoirs. While it would be exceedingly desirable and proper for the farmers to acquire all of the canals in the valley preparatory to the conservation of the surplus waters, the existing conditions are somewhat unfavorable for securing such control. In some instances large corporation canals are furnishing the water to small underlying community canals at a figure and in a manner satisfactory to the farmers, and the latter have no desire to change their method of delivery. In other instances the farmers now own and operate their canals on the cooperative plan, and these are also satisfied with their system of diversion. On the other hand, there are many farmers who are minority stockholders in large corporation canals, and these are of the class which most earnestly desires that the farmers of the valley should control the entire system of water delivery. The ranchers under the Mesa, Utah, and Tempe systems, owning their own canals, and being satisfied with them, generally refuse to bond themselves to acquire what are now large corporation canals, even though the plan is theoretically correct, and one which, if followed, would most likely save them much future trouble and litigation.

SILT.

The committee appointed to investigate the silting up of reservoirs on torrential streams failed to discover any great amount of written

matter on this important question. Some encouraging data were obtained concerning the operations of reservoirs already constructed in the Pecos Valley, New Mexico, where the conditions are somewhat similar to our own. Although these reservoirs have been in use a number of years, there has been no appreciable amount of silt deposit to date, and one theory advanced for this fortunate condition is that the beating of the waves against the sides of the reservoir as the water recedes washes the deposit down, thus keeping a considerable amount of silt continually in suspension, which is subsequently drawn off through the canals and wasteways. Instances were cited where reservoirs of great age in Spain, India, and portions of Europe were still in successful operation, and it was further pointed out that a number of instances existed in the West where large rivers passed through natural reservoirs in the shape of lakes, and had done so for ages, depositing therein their burden of silt, sand, and débris without causing any great apparent decrease in capacity. Notwithstanding these encouraging instances, however, it was realized by the members of the committee that the silt problem was one demanding careful study and consideration.

The writer has taken many samples of silt during flood times in the past ten years, and the maximum percentage of silt or mud (in volume) observed to date at this point is 8 per cent, while the maximum average of samples obtained during the flood periods for a term of three years was 5 per cent. A sample of silty water showing 10 per cent in volume of mud settled in the bottom of the graduated tube would probably indicate not over 2 per cent of actual solid matter.

While the amount of silt is large, it is not so great as is generally imagined by the farmers of the valley, who spend a considerable time after each heavy flood in cleaning silt deposits from the bottoms of their laterals and head ditches. They will also find the upper portion of the alfalfa borders built up several inches by a single irrigation during summer floods, and water tanks connected with laterals running muddy water show an astonishing amount of deposit in a very short time. In the first instance the average lateral or head ditch has a light fall, not sufficient to give a velocity of over 1½ feet per second, whereas water heavily loaded with silt requires a speed of at least 2½ feet per second in order that the silt may be kept moving and ultimately deposited on the irrigated lands. During a flood period a farmer's small head ditch, a mile in length, with a wetted surface which does not exceed 1 acre, may carry 100 acre-feet of muddy water through it before it becomes entirely choked up. The farmer, as he subsequently shovels out cakes of silt 6 inches in thickness, does not always take these things into consideration, and may be pardoned for a somewhat erroneous impression concerning the life of a reservoir. It is probable that he is more than compensated for the extra labor

involved in cleaning this mud from his laterals and head ditches by the fertilizing value of such silt as is deposited on his land.

To ascertain the probable life of reservoirs on the rivers would necessitate daily measurements of water and silt extending over a long period of years. Such data, unfortunately, are not obtainable, and any theories advanced as to the life of reservoirs on either the Salt or Verde rivers must therefore of necessity be more or less approximate.

AVAILABLE WATER SUPPLY.

Another problem carefully considered was that of the available water supply. Several members made a careful study of the question, but owing to the scarcity of reliable data concerning the flow of the Salt and Verde rivers, the conclusions were of necessity only approximations. The results of such measurements as were obtained indicated that in years of ordinary supply there was ample water to fill reservoirs on both the Salt and Verde rivers; but the records of flow for some of the dry years that have occurred lately demonstrated that it would always be wise to maintain a reserve supply in the reservoirs sufficient to tide over at least one year.

There is probably no other one thing within human power to accomplish which would increase the water supply to the extent that would result from the consolidation and subsequent protection of the forest reserves at the headwaters of our rivers. The storage committee aided in sending a delegation to Washington to interview the honorable Secretary of the Interior relative to this matter, and subsequently Messrs. Pinchot, Forester, and Coville, Botanist (both of the Department of Agriculture) were sent from Washington, at the request of the honorable Secretary of the Interior, to examine carefully the lands in question and make a report covering the entire matter. The citizens of the Salt River Valley are keenly alive to the importance of this question, and feel that, with property interests at stake which in the aggregate amount to nearly $30,000,000, they are entitled to have their earnest prayers for the consolidation of these reserves granted. It is possible that in the event reserves are made continuous a considerable amount of timber will be allowed to be cut under Government supervision, and probably grazing on certain portions of the reserve will also be permitted under proper restrictions, but the citizens of Maricopa County feel that only through such supervision on the part of the Government can the water supply be preserved, and that such control can not be exercised until the entire reserve is consolidated. There is now but little vegetation on these reserves to conserve and hold back the rainfall, and, as a consequence, the run-off after rains is rapid, the storm waters being precipitated directly into the river channels, reaching the valley in the shape of floods of short duration with waters loaded with silt, bringing down immense quantities of

brush, limbs, and trees to clog the head gates of our canals and seriously interfere with the diversion of the water. The river falls almost as quickly as it rises under these conditions, hence a large amount of water frequently passes the head gates of the valley canals and wastes to the sea, and before the farmer gets well started toward the irrigation of his thirsty lands the flow has subsided. It is not contended that the overgrazing of our drainage area and destruction of our forests are alone responsible for these changed conditions, as we have had some dry years of late in common with the entire Southwest, but it is generally believed that the unprotected condition and abuse of our forest reserves is the chief factor in the curtailment of the available water supply.

THE FOWLER BILL.

The committee worked diligently on one other matter, viz, the preparation of a bill to present to Congress asking that Maricopa County should be allowed to bond itself for the sum of $2,000,000 for the purpose of reservoir construction. Owing to the necessity for great haste in the preparation of the bill, many flaws were detected by the experts at Washington to whom the bill was submitted, and consequently it was not introduced into the House. It was then deemed wise by the committee to obtain at least some Territorial legislation in the interest of water storage, and mainly through the efforts of the chairman, Mr. B. A. Fowler, who was also a member of the house in the twenty-first legislature, the following bill was prepared and introduced, passing both houses and becoming a law. On account of its somewhat unique character and the important interests which it was designed to further, it has been thought best to include it in full.

SECTION 1. Any county in the Territory of Arizona having an assessed valuation of eight million dollars or over may avail itself of the benefits of this act by complying with the provisions as hereinafter provided. The board of supervisors, upon the petition of fifty qualified electors and freeholders of said county, shall request the district judge of the district in which the county is located to appoint a board of water-storage commissioners, and the judge shall within ten days thereafter appoint five qualified electors, who shall be resident freeholders of said county, who shall be known and designated as the board of water-storage commissioners. Each of said commissioners shall hold office for one year and until his successor is appointed and qualified. Before entering upon the duties of his office he shall give bond in the sum of one thousand dollars, payable to the said county for the faithful performance of his duty. Said bonds shall be approved by and filed with the board of supervisors of said county. At its first meeting the board shall organize by the election of one of its members as president. It shall also elect a secretary, who may or may not be of its number. The compensation for the members of said board shall be five dollars per day for each day actually employed. They shall also be allowed their actual traveling expenses. The salary of the secretary shall be fixed by the board. The board shall establish and maintain an office at the county seat of the said county. It shall be the duty of said water-storage commissioners to examine reservoir sites, cause to be made surveys and soundings, determine the capacity and estimate the cost of construction of said proposed reservoir or reservoirs, dam or

dams, determine the extent of the watershed and rainfall thereon; to collect such other information as shall show the water available for storage use in said county for irrigating purposes; to provide for the accumulation of such other information as may be required therefor and cause abstracts therefrom to be published in some newspaper published and of general circulation in said county; to employ and fix the compensation of a competent engineer or engineers; to prepare plans, specifications, and estimates for said reservoirs and dams, and file a copy of the same with the clerk of the board of supervisors of said county; to employ and fix the compensation of legal counsel in any matters arising under this act or necessary to authorize the construction of the dams or reservoirs referred to in said act, and to select the most available reservoir site or sites, and to acquire the same, together with any rights of way necessary, over public or private property, by purchase or through eminent domain, in the name of said county of Maricopa, and for the benefit of the people of said county, and to negotiate with and obtain agreements from canal companies in relation to the distribution of water or its delivery to the point of ultimate use, and to cooperate with or contribute toward the expenses of any investigations now being made or hereafter to be made by the United States Geological Survey, and to transfer to the National Government any reservoir site or rights therein or thereto or connected therewith, which may have been acquired hereunder, in the event that the National Government should undertake the construction of the reservoir.

SEC. 2. For the purpose of defraying the expenses of the board of water-storage commissioners the board of supervisors of any county availing itself of this act shall, at the time of levying Territorial and county taxes, in the year 1901 and in the year 1902, levy an additional tax of one and one-half mills on the dollar on all taxable property within the said county, to be collected as other taxes are collected, and the same shall be denominated and known as a water-storage fund. The board of water-storage commissioners shall audit and approve all bills for expenses incurred under the provisions of this act, and present the same, together with the claims for their salaries and expenses, to the board of supervisors, who shall, if found correct, pay the same out of any money in the water-storage fund.

SEC. 3. All acts and parts of acts in conflict with the provisions of this act are hereby repealed.

SEC. 4. This act shall take effect and be in force from and after its passage.

Approved March 20, 1901.

With the passage of the above bill the active work of the original storage committee ceased, although it was thought best to maintain the organization for some time, at least, with the hope of further usefulness in cooperating with the storage commission proper. The latter organization, with funds at its disposal, was enabled to immediately enter into practical cooperation with the Geological Survey in continuing the investigations of reservoir sites begun in connection with the original committee. The work is being carried on as previously outlined, and it is expected that later a full report will be made to the citizens of the Salt River Valley by the storage commissioners covering all the questions touched upon in this report and many others vitally essential and requiring careful consideration previous to the final recommendation of a definite plan of action.

It has been thought that the above brief résumé of the actions of our citizens in their efforts to improve their condition as regards a permanent water supply might be of some interest to citizens of localities

similarly situated, and unfortunately there are many such scattered throughout the arid West whose supply of water depends upon an inadequate and variable torrential stream.

PROPOSED LEGISLATION.

THE IVY BILL.

It has been mentioned that an effort was made on the part of a subcommittee of the general storage committee to prepare a bill for the improvement of the irrigation laws of the Territory. The bill prepared was not entirely satisfactory to the general committee, hence it took no action regarding its introduction. A similar bill, known as the Ivy bill, was, however, introduced into the legislature, and created more of a sensation in Salt River Valley than any other measure introduced during the session. The first four sections of the proposed act are as follows:

SECTION 1. All streams, lakes, and other collections of water capable of being used for purposes of irrigation are hereby declared to be public.

SEC. 2. Owners or occupants of arable and irrigable lands shall have the right to appropriate and divert the water necessary for the cultivation of the same.

SEC. 3. Priority of appropriation shall give the better right; land to have precedence according to the length of time it has been irrigated.

SEC. 4. A cubic foot of water per second of time shall be the legal standard for the measurement of water in the Territory, both for the purpose of determining the flow of water in the natural streams and for the purpose of distributing water therefrom.

The remainder of the bill followed closely the lines of the irrigation laws of Wyoming, dividing the Territory into four water divisions, creating the office of Territorial engineer and defining its duties, providing an assistant engineer, creating the offices of division superintendent and water commissioner, constituting a board of irrigation to consist of the Territorial engineer and the four superintendents and defining the duties of the same. It further specified the manner of adjudicating claims to streams, taking of testimony, determining priorities, issuing certificates of appropriation, and defined the course to pursue in instituting proceedings on appeal to the district courts from decisions of the board of irrigation.

The friends of the bill contended that such a law was needed for the carrying out of laws now on our statute books; that its purpose was to wed the water to the land and eliminate all so-called floating water rights; that inasmuch as the duty of water was not specifically determined in the bill, it could be made sufficiently elastic to match, in a degree at least, the variable water supply, thus giving the division superintendents power in a period of low water to divide the supply in a manner that would best subserve the interests of the entire community. As an instance: It would be manifestly ruinous to the valley

to fix an arbitrary duty of, say, 1 cubic foot of water per second to a quarter section of land during the summer months, thus confining at times the entire flow of the river to less than 20,000 acres of old alfalfa land. Should this be done, it would be the ruination of hundreds of acres of orchards and vineyards which the entire valley is interested in carrying over periods of scant supply, although irrigated subsequent to the alfalfa lands mentioned.

It was further agreed that well-defined legislation on this most important question was the only means by which the citizens of the Territory could be protected in their rights, regardless of the geographical situation of their ranches in respect to the stream (including its tributaries) from which they received their supply. This last contention is not without weight, as illustrated in our neighboring community surrounding the town of Florence, on the Gila River. In 1890 this little section was well cultivated and prosperous, with a good water supply fairly ample to its requirements even during the summer season. Since that date settlers have located on the Gila River many miles above Florence, in Cochise and Graham counties, and are at present diverting nearly all of the low summer supply, leaving the early settlers' ranches in the vicinity of Florence practically without water. Such a condition is deplorable, and the settlers in the Salt River Valley may suffer similarly, in a degree at least, owing to the diverting of the water from the Verde River. This stream is the chief tributary of the Salt River, furnishing nearly half of the summer supply. The continually increasing diversion of its water by later settlers on the Upper Verde is already causing a great diminution of water in the Salt River Valley during the summer season, and unless steps are soon taken to prevent further appropriations from the stream it is probable that the entire flow of the Verde River in periods of scarcity will be absorbed.

It is contended by some of the settlers on the Upper Verde that the diversion of water from the river at points from 30 to 100 miles above the canals of the Salt River Valley does not materially affect the water supply of the latter, owing, they claim, to the considerable amount of water which seeps back to the river channel after its application to their irrigated lands. This might be true if the settlers used water on these lands during the winter season and throughout every flood period, as is the custom with the canal systems in the Salt River Valley. Unfortunately, they do not irrigate extensively when water is thus abundant, but wait until lower stages of the river, using water liberally during the months of June and July, when it is usually at low ebb. Under such a method of diversion, it is probable that not over 25 per cent of the water used finds its way back to the river for use on the lower lying lands. From reports of an investigating committee of the Salt River Valley, who measured and examined the canals of the Upper

Verde during the summer of 1901, farmers of that section were diverting nearly or quite 1 "inch" of water per acre of cultivated land at a time when the rancher of the Salt River Valley was forced to get along with 1 inch to over 20 acres.

It is apparent to anyone familiar with local water suits that it would be a tedious and expensive matter to engage in litigation with citizens of another county where the irrigation districts in dispute are over 50 miles apart. The communities would fight to a man, one against the other, and testimony on which a just adjudication of priorities could be established between the two districts would be hard to obtain.

Under the proposed law this bar to an equitable adjustment would be removed, as each irrigator on a stream whose waters were about to be adjudicated would be asked to give the entire history of his water appropriation and farming operations from date of settlement. As every irrigator on the stream would be keenly alive to his own interests in the determination of his order of priority, and as the evidence submitted would be open to general inspection for several days after the completion of the taking of testimony, there would be small opportunity for mistakes or irregularities, as the findings would be most carefully scrutinized.

As regards the settlers on the Upper Verde or Gila rivers, there are undoubtedly many who have early and valid appropriations, and such could be protected by the enactment of a general Territorial law for defining and protecting rights. If the citizens of Arizona repudiate the doctrine of priority and refuse to consider legislation based on this principle, the settlers at the upper ends of streams will be a law unto themselves as regards water distribution, and courts will continue to be further clogged and burdened with expensive and tedious water litigation.

Another argument made in behalf of the bill was that laws of this character were imperative in view of the proposed construction of reservoirs by the citizens of Maricopa County. It was contended that unless wise laws should be enacted previous to reservoir construction it would be impossible to enlist the cooperation of the owners of lands entitled to early rights. Also, that in event of a reservoir being constructed such laws would be necessary in the distribution of impounded water.

The opposition to the bill was active, and meetings were held, where many arguments against the proposed measure were made. It was declared to be a menace to vested rights, and a measure which would, if it became a law, destroy many homes and reduce the irrigated acreage over one-half. The old arguments against the wedding of the water to the land were used, viz, that in many instances the earliest settlers had selected the low grounds immediately adjoining the river channel, which subsequently proved to be inferior land, either from

the fact that the gravel strata lay so close to the surface as to cause too rapid a drainage of the surface soil after each irrigation or that the constant saturation of the low lands for years, and consequent raising of the water plane, had brought alkali to the surface, which naturally decreased the value of the land. It was declared by the enemies of the bill that a law which would irrevocably attach water to such land, compelling a farmer to waste his energies in eking out a bare existence upon the same, was not a just one; that were he not chained to this inferior soil by reason of the doctrine of priority, he could abandon it entirely, and change his water to the more valuable high lands upon the mesas, where he would not only be benefiting himself, but the community at large. Another instance was cited where an early settler had the larger portion of his farm washed away by a high flood, and the Ivy bill, as applied to his case, was considered to be especially inapplicable, as being deprived of his land he would be left with a water right for which he had no use.

These latter arguments seem to be more theoretical than practical, however, in view of the existing conditions in the valley. There are a few instances where, on the low and early settled lands, the alkali was brought to the surface by the raising of the water plane. Some of these lands were abandoned on this account for several years, but are now being farmed with successful results, and are valued highly on account of their close proximity to the towns. Under the main trunk of the Utah Canal are located many early settlers on farms, some of which, at least, owing to the close proximity to gravel substrata, are considered much less productive and valuable than would be the higher mesa lands covered by or capable of being irrigated from their extended canals. These pioneers do not abandon their low lands, notwithstanding that the present method of water distribution as carried out gives them liberty to reclaim desert soil with their water should they choose to do so. Some of these early settlers, however, sold a number of their so-called water shares to newcomers from time to time, the latter settling on desert lands under what is known as the Utah Extension Canal. One of the most popular arguments against the Ivy bill, therefore, was that these pioneers having sold, to all intent at least, a portion of the water from their ranches, would, under the operation of such a law, be entitled to receive it back on their old lands in times of scarcity, leaving the innocent purchaser with only an empty right of way on his hands. This argument would have more weight were the selling of water not opposed by the laws on our statute books and the principles laid down by the "Kibbey decision." According to some of our leading lawyers, the man who purchases a so-called share of water in a canal is in reality acquiring but a right of way in the canal through which to flow such water as his land is entitled to receive by reason of its order of priority. This seems a harsh interpre-

tation of our laws; but if it is the correct one, the sooner this fact becomes generally known the better.

It was admitted by friends of the bill that in event of its passage there would be many complex problems to be solved in the proper distribution of the water supply, but inasmuch as such questions must be settled ultimately it was thought that the sooner definite administrative laws were put in force the better it would be for Arizona. It is possible that the bill was premature, since the citizens of the Territory had no time to study it previous to the convening of the legislature, but that its effect was good is generally admitted, as it aroused interest in this important question such as had not been awakened for many years, and although the bill did not pass it is felt that the labor and time spent in its preparation were not entirely lost. It is hoped that the canal owners, farmers, lawyers, and engineers from all parts of the Territory may cooperate in the preparation of a wise and just bill to present to the next legislature which will meet with the approval of that body and become a law.

IRRIGATION AT THE ARIZONA EXPERIMENT STATION FARM.

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LOCATION, WATER SUPPLY, AND SOIL.

The station farm, where the records that are the basis of this report were made, is situated 2 miles northwest of Phoenix in the midst of typical Salt River Valley farms, the region surrounding it being devoted to the production of alfalfa, grains, orchard and small fruits, and vegetables.

The station farm, as do other farms of the section, receives water from two (the Maricopa and the Grand) of the four main canals supplying the portion of the valley lying on the north side of Salt River. The amount of water received from these canals fluctuates very much during the year, varying with the flow of the Salt River from which they receive their water. Although the rainfall is heavier in the watershed of Salt River during the summer than during the winter, the flow of the river is usually much greater during the latter season. The parched condition of the watershed and the rapidity of evaporation during the hot summer months are undoubtedly responsible for the failure of most of the rainfall of that season to reach the valley below. During the months of December, January, and February an average of over three times as much water is available for irrigation as during the summer period of most abundant rainfall on the watershed. Consequently water is applied at the station farm, and upon

other farms of the region, not when most needed, but when it is available. This is a condition that naturally exists where flood waters are not stored.

The soil of the portion of the farm upon which was kept a record of the irrigation operations is a clayey, gravelly loam underlaid with gravel. The loam is 5 to 6 feet deep and the gravel beneath about 8 feet deep, below which lies about 20 feet of fine clay. Water does not percolate rapidly through the loam stratum, but when it once reaches the gravel it passes downward rapidly until the clay is reached. Hence only deep-rooted crops, such as alfalfa and fruit trees, are much benefited by water that passes beyond the stratum of loam. Determinations of the maximum water capacity of the soil of this upper stratum show that the depth of water required to saturate it is approximately 2½ feet. Determinations of moisture content made from samples taken a few days subsequent to irrigation, when superfluous water applied had time to settle away, showed that the soil as it lay above the gravel had the power to hold enough water to cover the surface to a depth of about 1¼ feet. Hence the latter amount is about what would be necessary to apply to this soil, if thoroughly dry, to put it into good condition for producing any of the crops reported upon, except the orchard fruits. Moisture determinations made when the soil was so far dried out that most crops would suffer for water showed the presence of a little over one-half foot of water in the loam stratum of 5½ feet. Thus the amount of water that might be economically applied at any irrigation would be theoretically the difference between 1.2 feet and 0.5 foot, or about 0.7 foot. This agrees very closely with the amount that experience has shown to be necessary to apply to bring soil in which most crops would suffer to a good state of moisture.

SEASON OF GROWTH.

Although there is no season of the year when some crop or crops are not growing on the station farm and on the other farms of the region, yet there are two seasons during which most are produced: (1) November to March, inclusive, when grains, most hardy vegetables, and small fruits are planted and make the main part of their growth, and (2) April to October, inclusive, when melons and other vegetables more sensitive to frost than to heat, corn, cowpeas, and sorghum make the most of their growth.

But there is no time of the year when some crops are not maturing and others in the early stages of their growth. The time when fewest crops overlap in this way is at the time of the first fall frosts, which occur about the middle of November. At this time the summer crops sensitive to frost are either mature or are killed, and few of the winter crops are planted. Hence this is the most appropriate time to make

a beginning of the crop year. The irrigation year reported upon below is considered as extending from the end of November, 1900, to the end of November, 1901.

RAINFALL DURING YEAR.

While precipitation may occur at any time of the year, in the vicinity of Phoenix there are two seasons during which the fall is heavier than during the remainder of the year, and the consequent supply of irrigation water much greater. The greatest precipitation usually occurs from July to September, inclusive, the other rainy season occurring from December to February, inclusive. The rain and snow falling in the mountains during the latter period usually furnish an increased supply of irrigating water until the end of March. From the latter month until July the rainfall is light, and the supply of water usually gradually diminishes, becoming very low during June. The summer rains swell the streams and increase the supply of irrigating water temporarily. Then follow about three months during which the supply is again usually less than the demand. The following is the precipitation of the year as recorded at the station farm:

Rainfall for 1901, Arizona Experiment Station farm, Phoenix.

Date.	Inches.	Date.	Inches.
January 25	0.38	July 27	0.05
January 27	.04	July 29	.59
February 1	.36	July 30	.02
February 3	.02	August 1	.06
February 6	.68	August 3	.97
February 7	.05	August 4	.01
February 10	.11	August 5	.02
February 11	.01	August 11	.22
February 24	.03	August 12	.06
March 8	.09	August 13	.05
March 31	.14	August 17	.14
May 14	.15	August 29	.21
May 29	.06	October 29	.55
July 2	.01	November 12	.13
July 23	.08		
July 24	.07	Total	5.36

The total amount of precipitation was considerably below the average, that of the previous four years, of which a record has been kept at the farm, being 6.16 inches. The small amount that fell, being divided into thirty showers, was of little direct benefit to the growing crops, the principal benefit being due, as was stated in the report for last year,[a] to the temporary raising of the relative humidity of the atmosphere near the surface of the soil, thus checking evaporation and causing more of the irrigating water to be available to the growing plant. If a rain can be followed with an irrigation, that the moistening of the soil may be continued downward to the moisture

[a] U. S. Dept. Agr., Office of Experiment Stations Bul. 104, p. 126.

below, then the rain may be a distinct benefit. In any case, shallow-rooted crops are temporarily benefited, but unless a cultivation follows the soil at and near the surface usually soon becomes baked and the crop is often worse off than before the rain. The crops benefited most by the local rains are the winter grains. Being shallow-rooted and growing during the cool time of the year, when evaporation is less rapid than at other times, they often receive considerable benefit from the rains of December, January, and February. It will be noted that during the above period of the past season three rains, varying in amount from one-third to two-thirds of an inch, occurred that would benefit growing grain. But the total amount for that period (1.68 inches) is small compared with the amount required to produce the crop. One of the July showers, that of the 29th, and one in August, that on the 3d, also benefited considerably some of the summer crops, such as strawberries, tomatoes, and cotton. Possibly an average of a tenth of a foot might be counted as the amount of rain utilized by each crop in addition to the irrigating water applied.

The rainfall of the year was not distributed quite as it usually is. The greatest amount fell during the summer, but none fell during either December or September, months during which one-half inch to 1½ inches usually falls. It will be noted that during March, May, and the most of July the rainfall at no time was sufficient to wet dry soil to a greater depth than one-half inch, that none fell during April or June, and none during the two months from August 29 to October 29.

Of greater importance than the local rains are the storms in the mountains constituting the watershed of the Salt River, from which the irrigating water is drawn. Of these we have no record.

TEMPERATURE AND RELATIVE HUMIDITY.

The coolest months at the station farm are December and January, during which frosts, occasionally heavy ones, are frequent. During February the weather commonly becomes gradually warmer. It may be considered that this month marks the beginning of spring. The principal part of the growth of winter-sown crops is made during the three months that follow. During these three months the weather becomes increasingly warm and continues to do so during the following month, the maximum temperatures by the latter part of June ranging from 100° to 115° F. in the shade. The relative humidity of the atmosphere decreases as the season advances and the temperature rises, evaporation consequently becoming very rapid. During July, August, and September the weather is as warm as, or warmer than, during June; but the humidity is temporarily increased from time to time by rains, and the weather is consequently less trying upon vegetation.

From September to December the weather grows cooler gradually and the relative humidity usually increases.

The following averages of the monthly mean temperature and the mean relative humidity at the farm for each month of 1901, and for the five years previous to 1901, will indicate the changes in the weather from season to season of the year, and will also show how the past year has differed from the average of the preceding ones:

Averages of monthly mean temperature and mean relative humidity at Arizona Experiment Station farm.

Month.	Mean temperatures.		Mean relative humidity.	
	1896-1900.	1901.	1896-1900.	1901.
	° *F.*	° *F.*	*Per cent.*	*Per cent.*
January	49	52	53	47
February	55	55	42	59
March	56	59	38	38
April	66	64	33	29
May	73	73	26	30
June	83	81	24	19
July	89	91	37	33
August	86	88	40	43
September	81	81	39	28
October	67	71	40	39
November	57	61	43	49
December	49	*a* 52	45	*a* 42
Means	67.6	69	38.3	38

a 1900.

It will be observed that the mean temperature of the year has been greater than the average of the period 1896–1900, April and June being the only months in which the average was below the average of the same months from 1896 to 1900, and the mean temperature of the year averaging for each day about 1½° above the average for 1896–1900.

The relative humidity has fluctuated considerably, some months being above the average, others very much below the average, the mean for the year being a little below the average.

It will thus be seen that the year has not been a normal one. The rainfall has been below the average, the temperature has been considerably above, and the relative humidity slightly below. These conditions all conspired to make the amount of irrigating water necessary greater than usual. Hence the duty of water, as shown by the table on page 105, is probably somewhat above the average.

EVAPORATION.

The record of evaporation from a water surface has not been kept at the farm for a full year. A beginning was made last May, and a record is now being kept regularly. The results for May to Novem-

ber, the end of the irrigation year, inclusive, are given in the table that follows:

Evaporation at Arizona Experiment Station farm from May, 1901, to November, 1901.

Week ending—	Evaporation.	Week ending—	Evaporation.
	Inches.		*Inches.*
May 7	1.68	September 3	1.56
May 14	1.92	September 10	1.68
May 21	1.92	September 17	1.80
May 28	2.04	September 24	1.68
June 4	2.04	October 1	1.56
June 11	2.16	October 8	1.32
June 18	2.04	October 15	1.08
June 25	2.28	October 22	1.08
July 2	2.28	October 29	.84
July 9	1.92	November 5	.48
July 16	2.52	November 12	.....
July 23	2.64	November 19	.36
July 30	2.52	November 26	.48
August 6	2.88	December 3	.48
August 13	.72		
August 20	1.44	Total	49.08
August 27	1.68		

The total of the seven months, approximately 49 inches, was divided among the months as follows: May, 8.28 inches; June, 9.42 inches; July, 11.29 inches; August, 6.55 inches; September, 7.08 inches; October, 4.81 inches, and November, 2.05 inches. At this writing the record for December is complete, and the amount of evaporation is very little less than that of November, and January will probably be about the same. From the latter month on, the increase in the mean temperature and the decrease in the mean relative humidity naturally causes a gradual increase in the monthly evaporation. The total for the past year was probably about 70 inches. It will be noted that though the temperature was higher during August than during September, the evaporation was greater during the latter month. This was due to the frequent showers of August and the absence of rain during September. From the latter month to the end of the year the rate of evaporation decreased gradually and quite regularly.

METHOD OF MEASURING WATER.

A record of the depth and duration of each "run" of the water flowing through the ditch that supplies the 28 acres of the station farm involved in this report, and a few small farms lying below it, is made by a water register situated at one side of a gauge box placed in the ditch at the upper margin of the farm. A Y-shaped division box a short distance below the register separates the portion to which the station farm is entitled from that which is to flow on through to the farms below. The station contracted with the canal company for the delivery of 33⅓ inches (the amount of its so-called water right, an inch being supposed to equal one-fortieth of a cubic foot per second) from the Grand Canal and 10 inches from the Maricopa Canal. The farmers below had contracted for the delivery of 40 inches of Grand Canal water and 25 inches of Maricopa water. Thus, when water was flow-

ing from the Grand Canal, whatever water was flowing in the lateral was divided in the proportion of 33⅓ to 40; and when water was flowing from Maricopa Canal the station was entitled to ten thirty-fifths, or two-sevenths of the total amount. These fractional portions of the amount that, according to the water register, passed through the ditch are taken as the quantity used upon the 28 acres of the station farm during each of the different "runs." It is to be understood that after contracting with the canal company, which, under our existing system, has entire control of the distribution of water, the station has no voice as to the amount of water that shall pass through the ditch leading to the farm, its only prerogative in the matter being to properly separate its portion from the remainder of the water in the ditch.

The amount of water (as determined by the above method) used upon the 28 acres of the station farm involved in this report during each month of the year December, 1900, to November, 1901, was as follows:

Water used on station farm, December 1, 1900, to November 30, 1901.

Month.	Acre-feet.	Month.	Acre-feet.
December	8.4	July	8.9
January	17.6	August	17.6
February	23	September	6.4
March	22	October	8.1
April	20.2	November	6.1
May	13.6		
June	8.3	Total	160.2

By a comparison of the above monthly amounts of water received at the farm and the rainfall record for the year (p. 101) it will be seen that there is a close relation between the two. The flow of water in the ditch fluctuated with the flow of the river as modified by the storms in its watershed. No rain falling during December, the amount of water available for irrigation was small. The rains of January increased the flow of the river and the amount of water in the canals. During February, owing to heavy rains in the watershed of the river, the maximum amount that the canals and irrigating ditches would carry was distributed to the farmers. The amount received and used upon the farm during that month was, according to the water register, 23 acre-feet, sufficient to cover the entire 28 acres to a depth of 0.82 foot, or nearly 10 inches. A large part of this was used upon the orchards, which were irrigated heavily during the winter. During the succeeding two months, owing to the melting of a snow in the mountains and to light rains, the amount delivered at the farm continued high, the amount received during the first four months of the calendar year being over one-half of the total amount received during the year. During May, June, and the most of July the amount received gradually decreased. The rains of the latter part of July and of August increased the flow in the canals, the amount received during the latter month equaling that of January. During the

remainder of the year, with the exception of a brief period following the October rain, the flow remained low. The times of the year when the small amount received affected field operations most was during the latter part of May, during June and July, and again during September and October. The weather being warm and dry during these months, an increased rather than diminished irrigation was needed, emphasizing the importance of having stored for summer use the water that flowed down the river to the ocean during winter.

The total amount received at the station farm, 160.2 acre-feet, was only a small portion of that contracted for with the canal company. Experience having shown that only a small proportion of the amount contracted for is ever delivered, farmers have adopted the custom of contracting for and paying for the delivery of much more than they could possibly use. It being especially important that operations at the station farm be not interrupted by a shortage of irrigating water, the aim has been to contract for enough to as nearly meet the requirements as possible. Hence, as has been stated, the delivery of 43⅓ inches, or a little over 1 cubic foot per second, was paid for by the station in advance at $2.25 per inch, a total of $97.50 for the 28 acres, or $3.48 per acre. Besides this amount the payment of $53.35 yearly for a so-called water right was required by the canal company, making a total of $5.39 per acre per year for the irrigating water used. The total amount received equaled an average of 13.35 acre-feet per month, or a continuous flow of approximately 9 inches, instead of the 43⅓ inches contracted for. Even during February, the month of greatest flow, when all canals and ditches were carrying the maximum quantity that their capacity enabled them to carry, only an equivalent of 15⅓ inches continuous flow was received at the farm, indicating that it would not have been possible under any circumstances to have delivered to all consumers the water for the delivery of which each had contracted and paid through the canals the company were operating.

The total depth used upon the station farm equaled an average of 5.7 feet. This amount is somewhat larger than would be necessary to produce the same yields during an average year, as has been stated in the discussion of the weather conditions of the past year. It is also to be understood that upon several fields two crops were grown during the year—in one field melons and corn following potatoes, in another corn following melons, and in a third clover following grain. Furthermore, to part of the orchard more water than was essential was applied during the winter when the supply was in excess of the immediate demands of the growing crops. The fluctuation of the water supply causes a much smaller crop return than would be obtained from the same amount delivered as needed during the year; or, to state it another way, the same results as those obtained during the past year might have been obtained with a considerably smaller water supply had it been delivered as the crops needed it. Six of the 28

acres lay idle from May to November because of the water supply being insufficient during these months to cultivate all the farm, and the yield of several crops would have been greater had it been always possible to apply water at the most advantageous time.

WATER APPLIED TO INDIVIDUAL CROPS.

A record was kept of the water applied to the principal crops grown upon the station farm during the past year. For determining the amount applied at each irrigation, gauge boxes were installed at necessary points upon the farm, and the length of time that water ran upon a given crop at each irrigation, and the depth in the box, noted and recorded by the employee doing the irrigating.

From a record kept of the work done on each crop, and from data secured from farmers, an estimate, believed to be fairly accurate, was made of the cost of the production of each crop.

The gross value of the crop per acre was estimated chiefly from a record of actual returns from produce sold. In case a crop, or a portion thereof, was not sold, it was credited with what it would have brought upon the market at the time it was harvested. The following table gives the data regarding the use of water on the various crops:

Record of crops grown on station farm, 1901.

Crop.	Water applied previous to planting.	Date of planting.	Date of first irrigation.	Date of last irrigation.	Number of irrigations.	Depth of water applied during growing of crop.	Total depth applied.
	Foot.					*Feet.*	*Feet.*
Wheat sown in moist soil	0.6	Nov. 26	Mar. 4	Apr. 6	3	1.6	2.2
Wheat sown in dry soil	.0	....do...	Dec. 8	....do...	4	2.5	2.5
Wheat sown in moist soil	.6	Dec. 5	Mar. 5	Apr. 11	3	1.5	2.1
Do	.6	Jan. 3	Mar. 7	Apr. 14	3	1.5	2.1
Potatoes	.7	Jan. 9	Mar. 17	May 10	4	1.7	2.4
Do	.7	Feb. 1	Mar. 27	....do...	3	1.3	2.0
Do	.7	Feb. 22	....do...	....do...	3	1.3	2.0
Tomatoes	.6	Feb. 14	Feb. 26	Oct. 28	27	3.7	4.3
Strawberries	.7	Feb. 16	Feb. 16	Dec. 26	36	5.5	6.2
Melons	.7	Mar. 16	Mar. 26	July 8	12	2.6	3.3
Egyptian cotton	.7	Mar. 30	Apr. 11	Oct. 3	13	4.3	5.0
Corn	.6	Aug. 3	Aug. 9	Oct. 7	5	1.5	2.1

Crop.	Date of harvesting.	Yield per acre.	Gross value per acre.	Cost of producing and marketing crop per acre.	Net value per acre.	Net return per acre-foot of water applied.
		Pounds.				
Wheat sown in moist soil	May 22	2,150	$22.55	$10.25	$12.30	$5.60
Wheat sown in dry soil	.....do	1,850	19.40	9.65	9.75	3.90
Wheat sown in moist soil	May 24	2,120	22.25	10.20	12.05	5.74
Do	May 30	1,920	20.15	9.95	10.20	4.85
Potatoes	.....do	3,200	80.00	35.00	45.00	18.75
Do	May 25	3,600	85.00	34.50	50.50	25.25
Do	May 30	3,000	70.00	34.50	35.50	17.75
Tomatoes	July 1 to Dec. 9	12,300	225.00	75.00	150.00	34.90
Strawberries	Apr. 15 to July 15	5,000	500.00	150.00	350.00	56.45
Melons	June 15 to July 15	27,000	140.00	26.00	114.00	34.55
Egyptian cotton	Dec. 14	400	68.00	48.00	20.00	4.00
Corn	Dec. 10	1,735	18.00	9.50	8.50	4.05

WHEAT.

There are two methods of putting in wheat in southern Arizona. Either the fields are plowed quite dry and, after being harrowed, sown in this condition, or the fields are thoroughly irrigated before plowing and the seed sown in moist soil. If the former method is followed, irrigation as soon after sowing as possible is necessary to cause germination of the seed. If sown in moist soil and covered deeply with an ordinary harrow or with a disk harrow, it will usually germinate well and make a good stand without irrigation following the sowing. The results from the two methods of putting in grain are consequently quite different. Irrigating the dry soil after sowing the grain causes it to bake and the surface to remain in a hard condition unless a harrow is run over the field before the grain is large enough to be injured. In any case the condition of the soil is such that another irrigation will be needed before that sown in moist soil will show the need of water. The compacting of the soil by the irrigation following seeding causes the loss of moisture to proceed more rapidly than from the fields sown in the other way, and the consequent need of earlier and more copious irrigation. Fields in which the seed is sown in moist soil usually need no irrigation for two or three months, during which the grain will make an excellent growth and send its roots deeper than in the soil that is irrigated soon after the sowing of the seed. By the time the moisture stored in the soil before sowing is evaporated and used by the plants, the surface of the field will be covered by the growing grain. Consequently, when water is applied, evaporation from the surface of the soil is not as rapid as it would be from bare soil, and the soil does not bake, as in the case of that irrigated when bare. Hence the soil of such fields remains in much better condition than that in those irrigated soon after seeding, and the grain has an opportunity to make a better growth and give a larger yield.

It will be noted by referring to the table on page 95 that the wheat sown in moist soil not only required less water to bring it properly to maturity, but that the yield was greater. The amount of water used was about a seventh greater on the field sown dry, while the yield was about a seventh less than from the other field. This makes quite a difference in the net returns per acre as well as in the net returns per acre-foot of the water applied.

The season of sowing wheat in the region extends from the early part of November to the 1st of February. It will be noted that three sowings of wheat were made in the moist soil, the aim being to have the conditions all the same, except the time of sowing, there being about nine days between the first two sowings and about a month between the second and third sowings. It will be seen, however, that the difference in yield from these three fields was not great, there being

only a slight difference between the yields from the first two sowings, and a yield of only 200 pounds less from the sowing of January.

The cost of producing and marketing the wheat crops was estimated, not from our own records, but from data obtained from wheat growers, wheat harvesters, and wheat buyers. Our plats were only from one-half to three-fourths of an acre in size, and consequently operations were conducted on too small a scale to furnish a basis for an estimate of the cost of producing the grain. The plats were cradled and the grain bound and then thrashed with a flail in the old way, while none is so harvested by grain owners. Either the grain is headed, stacked, and thrashed later on or havested by the combined header and thrasher, making the cost of harvesting much less than it would be by the method followed. The gross return per acre is based upon the price paid for the wheat at the mills soon after harvesting time.

POTATOES.

The principal object of the experiment with potatoes during the past season was to determine the results from planting them at different times during the two winter months of January and February. As stated in the report for last year,[a] potatoes planted January 17 gave a considerably greater yield than those planted three weeks later and given the same amount of water. As stated there, the results would probably have been different from the plantings made at the same time during a less mild winter than that one. The past winter was less mild, and verified the correctness of the opinion expressed in the previous report. The potatoes planted January 9, as will be seen by reference to the table, gave a lower yield than those planted February 1. This was due to the frequent frosts that occurred during March. Those planted earlier were larger when the frosts came, and consequently sustained more injury than those planted later. On the other hand, those planted the latter part of February, did not have sufficient time to make a full growth before the warm weather of May, and consequently did not give so large a yield as those from either of the other two plats. Judging from the experience of the past three winters, during average years, the largest yield from a given amount of water applied may be expected from potatoes planted during early February. During mild winters a heavier yield may be secured from potatoes planted about the middle of January, but during no year, according to our experience, is it wise to postpone planting much after early February if a full return from the water applied is to be expected.

It will be seen that those planted January 9 were not irrigated for over two months and that those planted February 1 were not irrigated

[a] U. S. Dept. Agr., Office of Experiment Stations Bul. 104, p. 129.

for nearly two months. This postponement of the first irrigation was due to thorough irrigation before planting, and thus storing in the soil sufficient moisture to bring the potatoes up and enable them to grow 3 or 4 inches high without their growth being retarded for lack of water. Thoroughly irrigating the soil before plowing for planting makes possible this postponement of irrigation after planting and leaves the soil in a mellow condition that is very favorable to the growth of the crop. If potatoes are irrigated soon after being planted the soil becomes baked about the roots and as good a growth is not made as is made in mellow unirrigated soil. When irrigation is once begun the application of water must be frequent enough to keep the soil moist and prevent it at any time becoming hardened about the roots and growing tubers.

TOMATOES.

The third of an acre used for the experiment with tomatoes was planted much as corn is planted in an irrigated region. Instead of growing the plants in boxes under shelter the seed was planted directly in the field in hills. After plowing and harrowing, furrows were run 4 feet apart and the latter moistened by running water through them. As soon as they were sufficiently dry the seed was planted at their sides in the moist soil. During favorable weather the seed will germinate and the plants will make considerable growth before irrigation will be needed, but if the planting is followed by weather that is too cool or too dry for good growth, irrigation will be needed much sooner than otherwise, as it is not possible to cover such small seed deep enough for the soil around it to remain moist during dry weather.

It has been found from experiments at the farm that tomatoes give much more satisfactory results planted in the above manner than if grown first in boxes during cool weather and then set out when warm weather arrives. The young plants that grow from seed planted in the field endure a surprising amount of cool and even frosty weather without injury, and when warm weather comes begin making a vigorous growth. While during the cool period plants from seed sown in boxes will grow much more rapidly and attain a much larger size than those grown in the field, yet the transplanting of them in our arid climate so checks their growth that those planted in the field will soon pass them and will mature tomatoes earlier than those planted in boxes. Besides the above advantages, the method of planting them in the field is much less expensive than the other.

The main part of the crop was harvested during July, August, October, and November, very few having been harvested during September. During the past season, owing to the late frosts, more were harvested during October and November than during July and August. This would not be the case during every year, and the yield would

thus be less than during the past year. The yield during July and August does not differ so much from year to year, but the autumn yield depends very much upon the earliness of killing frosts. Regardless of the amount of water applied, however, tomatoes do not set during the warm weather of August, and consequently there are a few to ripen during September. As the weather grows cooler—even though it be drier—tomatoes begin setting, and ripen until heavy frosts occur, usually about the middle of November.

While the number of irrigations was large, yet the amount of water applied during the year was not proportionately great, as during much of the season it was only necessary to moisten the furrows along which the tomatoes were grown, much of the space between being left unirrigated. Only during the latter part of their growth did the plants occupy the whole surface of the ground, when the entire area of the field needed to be moistened.

STRAWBERRIES.

The strawberry plat upon which report is made was prepared and set in the way that is most common in the region. Ridges about 1 foot high were thrown up 3 feet apart, the soil moistened by running water through the endless ditch formed by connecting the ends of the ditches lying between the ridges, and the plants set at the upper line of where the water had run, or about midway between the bottom and top of the ridges. As soon as the plants were set, water was again run through the space between the ridges, and was applied subsequently frequently enough to keep the soil about the plant roots quite moist. As will be seen, the total amount applied was greater than that applied to any other crop of the year.

The estimates of the cost of production, the yield per acre, and the gross returns given in the table on page 95 were based upon not only the above plat, but upon the results from one a year older, and upon data obtained from growers who had larger fields of strawberries. The difficulty in carrying a field of strawberry plants through the first season after setting, especially during the past trying ones, and the increasing demand for the product causes the price of this fruit to remain high. The fact, also, that they require soil particularly adapted to their growth, as well as frequent watering, prevents their general cultivation in the valley.

There seems to be need of careful experiments to determine the best methods of irrigation and of culture, in order to secure the largest financial returns—a work that the station has undertaken and proposes prosecuting for some time. It is possible also that a number of varieties requiring less water, and otherwise better suited for culture by irrigation than the one commonly grown, may be found.

MELONS.

An acre of ground was planted to five varieties of melons, including the varieties most commonly grown in the region. They were planted 8 feet by 6, the rows being 8 feet apart and the hills 6 feet apart in the rows. The field was irrigated before plowing, and after plowing and harrowing furrows were run 8 feet apart and moistened with streams of irrigating water. As soon as the furrows were sufficiently dry, the seed was planted in hills along their sides. During favorable weather the seed will germinate and a good stand be secured without additional irrigation. But the past season the weather following the planting happened to be too cool for the satisfactory growth of melons, and an irrigation in ten days and a replanting was found necessary.

EGYPTIAN COTTON.

Having no previous experience in growing this crop, the three-fifths of an acre devoted to it was planted according to the method followed in Egypt, as outlined by Professor Foaden in United States Department of Agriculture, Office of Experiment Stations Bulletin No. 42. The land was first irrigated and, after being plowed and harrowed, furrows were made 3 feet apart. These were moistened with streams of irrigating water and the seed planted along the side when they were sufficiently dry. The seed germinated in sufficient quantity to produce a good stand without further irrigation until the plants were well up. During the following three months they were irrigated sufficiently often to keep the plants growing vigorously. When it began to be evident that they were likely to grow to too large a size if supplied with too much water, they were given just enough water and irrigated only frequently enough to prevent the leaves withering seriously during the heated part of the day. Notwithstanding this precaution the growth of part of the field was too rank and some of it lodged. It is now thought that the same yield might have been obtained with the application of less water than that applied during the past season, and that this amount will not be necessary to produce Egyptian cotton in this region. The amount given in the table as that applied was more than that actually used by the crop, as the rows were too short to permit of proper irrigation without considerable of the water applied running away at the lower end of the plat. In a large field with longer rows the percentage of water that escaped from the lower end of the field would be much smaller. The total amount necessary to produce a crop of this cotton is probably not very different from that needed to grow alfalfa.

The cost of production is probably placed higher than it would be in the case of larger fields. A large item of the expense was the picking of the cotton, which would not cost so much if it were grown on a larger scale and laborers become more accustomed to the work.

CORN.

This crop was planted later than it should have been, and later than it would have been had a supply of irrigating water been available earlier. Had frosts been as early as they are some falls, little, if any, ripe corn would have been secured, and the only result of the application of the water used would have been a crop of corn fodder.

The corn was planted in the usual way along previously moistened furrows, and then not irrigated until after it had come up. It will be noted that all the water the corn received was applied during the first two months after planting. During this period the corn made most of its growth, and required no further irrigation while it was maturing its ears. It will be noted that the total amount applied was just about the amount that is necessary to grow a crop of wheat, although the yield from the latter was somewhat greater. Like the wheat, the corn was benefited considerably by the rains that fell during its early growth.

CALIFORNIA.

STUDIES OF THE SUBTERRANEAN WATER SUPPLY OF THE SAN BERNARDINO VALLEY AND ITS UTILIZATION.

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THE VALLEY OF SOUTHERN CALIFORNIA.

That the drainage basins now occupied by the Santa Ana and San Gabriel rivers and their affluents were, in times not very remote geologically, a topographic unit, is clearly apparent from the continuity along the foot of the Sierra Madre, from Redlands on the east to near Pasadena at the western end of that range, of a series of remnants of a terrace or bench formation characterized by its conspicuous "red" tint, contrasting with the gray of the valley lands. In passing from Redlands, which derives its name from the color of the soil, to eastward of the town toward Grafton and across Mill Creek, we encounter between the latter and the Santa Ana canyons a recurrence of the red soil on a small plateau or mesa lying some 50 feet above the general level of the valley of the Santa Ana near by. Still going westward we see remnants of the same character along the foot of the range and on the canyon sides, mostly, however, as at East Highlands, somewhat commingled with the débris or talus material from the granitic rocks of the range above. Perhaps the most conspicuous and convincing outlier of the red terrace formation on the north side is the "Indian mesa," northward of Pomona, an abrupt elevation averaging about 50 feet above the general level of the adjacent lands and forming a plateau 40 acres in extent, the exact counterpart not only of the red mesa land farther east and near Redlands (Pl. VIII), but also of the uninterrupted terrace which runs from the mouth of the San Timoteo Canyon to East Riverside, and farther on, forming "Arlington Heights," back of Riverside, breaks off to westward into the narrow valley of Temescal Creek. It is continued beyond into the Auburndale Hills, which in their turn fall off to westward into the Santa Ana trough. Still westward we find the red formation on the slope of the hills to southward of Puente, whence it gradually falls off into the broad alluvial plain of the lower San Gabriel River. To northward again we meet the red loam at the foot of the Sierra Madre near Monrovia, Duarte, Azusa,

and Pasadena; and the red gravelly hills traversed by the California Southern Railroad between these points and Los Angeles are doubtless remnants of the same formation, together with the hill in that city, originally some 30 feet higher, on which the high-school building now stands.

At the time the red loam and underlying gravels were deposited the entire valley from Redlands to Los Angeles must have been submerged to the depth of some 700 feet above the present drainage level. How this submergence was brought about we have not at this time sufficient data to determine. Probably there was a depression to near the level of the sea, while these terraces are now about 1,350 feet above the same. The bay or lake, some 80 miles long and 12 miles in greatest width from the Sierra Madre to the foothills of the Santa Ana range, had then near the middle of its length an island, which at present is represented by the San Jose Hills, a broad ridge 9½ miles long from Puente, near its western end, to Pomona, at its eastern end. It lies considerably nearer (1½ to 2 miles) to the southern than to the northern edge of the valley (8 to 10 miles).

GENERAL CHARACTER OF THE DRAINAGE OF THE VALLEY.

Only an insignificant portion of the water supply of the valley comes from its southern margin, which is formed mostly by low hills. The governing factor of the hydrography is the Sierra Madre, from which descend all but one of the streams of the north side, viz, the Los Angeles River, which heads in the adjacent San Fernando Valley, or rather basin. All the rest come down from the rugged, precipitous canyons and slopes of the Sierra Madre, which falls off steeply into the valley, not only above the present land surface, but also, as borings made near its foot prove, to over 1,000 feet beneath the present drainage level, as is the case with so many of the broad Cordilleran valleys, and notably with the great central valley of California.

DÉBRIS FANS.

At the mouth of all the canyons descending from the Sierra Madre we find cone- or fan-shaped accumulations of bowlders and cobbles, over which the streams can pass only at times of flood, for at ordinary stages the water is completely absorbed in these coarse débris beds, and in the case of the smaller streams not reappearing on the surface at all, but passing into the main channels by seepage through the deposits of finer materials which have filled the valley farther out. Only the larger streams, such as the San Gabriel and Santa Ana, commonly flow visibly and continuously throughout the year, at least in their lower courses, while higher up their flood channels are more or less definitely marked by sandy "washes," in which water is sometimes, but not always, found at comparatively shallow depths. Of these

VIEW OF MESA NEAR RIVERSIDE.

washes there are usually several, some definitely abandoned, others occasionally occupied by the rivers in times of unusually high floods.

STRUCTURE OF DÉBRIS FANS.

It is interesting to consider what must be the structure of the valley deposits formed under the conditions which have evidently obtained here in the past, when the winter floods poured out their loads of coarse débris over steep slopes reaching 1,000 feet or more below the canyon mouths. Clearly, there would first be formed a steep half cone of bowlders and cobbles, leaning against the slope, with toe-like ridges of the same materials radiating out (fig. 3). Through this cone the water would find its way to the bottom of the valley and flow out from the foot of the cone, carrying with it the finer materials, which would then be deposited about the base and farther out, and gradually build up around the core of coarse materials a mass of less pervious

[illegible]

deposits, alternating with occasional irregular beds of gravel and cobbles carried by flood waters to a greater or less distance from the central cone. The central cone will remain permanently the reservoir of a pressure column from which the stored waters will flow outward with varying velocities and pressures, according to the levels and the perviousness of the materials penetrated. As is well known and easily intelligible, the channel or channels on débris cones or fans frequently shift from one side to the other, usually gradually, but sometimes abruptly, in consequence of an accumulation of bowlders (kames) left by some unusually heavy flood across the previous course of the stream. Wherever such a flood finds an opportunity for spreading out the cobbles and gravel will be left behind, and thus such deposits are rarely continuous for any great distance, except in the main channel of a deep valley; but even in such cases the deposit does not often remain directly connected with the gravel cone and the pressure column of water around the mouth of the canyon. This variability

and discontinuity of strata in débris cones, which can be seen on many sections, either natural or derived from the record of borings, implies that we can rarely expect to find similarity on the *cross* section of a fan, while to a limited extent we may look for a certain continuity in *radial* sections or directions. In many cases, however, pervious deposits connected with the central cone may terminate at or near the surface of the fan, especially where it has suffered subsequent denudation. When this is the case there are formed water-bearing lands, or "cienagas," such as are very commonly found in this valley and are highly prized as sources of irrigation waters, which are obtained by ditching, tunneling, or boring into the fans or alluvial deposits of the valley, according to the greater or less steepness of the slopes. On the steeper slopes flowing artesian water is usually obtained, while on the gentler ones the wells often require to be pumped, or ditches or drifts serve to collect the water absorbed within the porous beds.

THE SAN ANTONIO DÉBRIS FAN NEAR POMONA.

A conspicuous and typical example of such cienaga lands, extending practically across the entire valley and subdividing it into the San Gabriel and Santa Ana drainages, exists near the town of Pomona. Pomona lies close to the eastern end of the San Jose Hills, already alluded to. Between these hills and the town flows San Jose Creek, which, heading in a high-lying cienaga to northward of the hills, curves around their eastern end and pursues its course westward through the narrower southern division of the valley toward the San Gabriel River. Directly to the southward of this curve, and but a short distance away, heads Chino Creek, which, flowing eastward into the Santa Ana River, also traverses a tract of moist land, from which it receives the greater part of its water supply, the Puente Hills, in which its extreme heads lie, being very poor in springs.

It is interesting to inquire into the origin of these moist lands, or cienagas, the cause of their location on the water divide between the two river systems, and the cause of that division itself.

The latter point becomes evident at a glance when one ascends the hills to the southward of the divide and looks northward toward Bald Mountain, the highest summit of the Sierra Madre Range west of San Bernardino Peak. Right opposite lies the mouth of the San Antonio Canyon, and from this as a central point there diverges a gently sloping débris fan reaching to within a short distance of the hills opposite. (See map, Pl. IX.) The eastern and main portion of this fan drains toward Chino Creek, while the western third or thereabouts lies banked up against the eastern portion of the San Jose Hills, 150 to 175 feet above the southern valley, and forming what is known as the "Palomares Cienaga," in which San Jose Creek heads. Moreover, before the Pomona slope was settled, it was easy to trace several diverging lines

of sycamore trees from points near the apex of the fan down to its base; and in these cienaga belts it was easy to obtain water within a short distance of the surface in water-bearing gravel or cobbles. In some cases these sycamore belts were interrupted by grassy bogs of a few acres in extent, where water was at or near the surface, and the exuberantly fertile soil of which, almost sooty black, spoke of long accumulation of vegetable débris, for the benefit of the truck gardens which now occupy these muck lands. Wells bored in these tracts—the Martins and Del Monte cienagas—gave a plentiful supply of excellent water.

The past tense is used in this connection because cultivation and the diligent search for an adequate water supply for the town and orchards of Pomona have now obliterated many of these features. A number of wells were first bored by the Pomona Land and Water Company in the Palomares Cienaga which, being banked up against the San Jose Hills, promised to yield flowing water at a relatively high elevation, available for the higher portions of the settled district. Subsequently the boring of wells was extended to the eastward into what is now the town proper, increasing materially the total supply, originally drawn from San Antonio Creek alone. The flow of this stream is divided equally between Pomona and Ontario. Its usual summer flow, derived mainly from the snows of Bald and San Antonio peaks, is about 800 inches.[a]

The position occupied by the San Antonio débris fan, and the well-known fact that the channels of fan-forming streams migrate in the course of longer or shorter periods from one side of the fan or cone to the other, renders it certain that in the past the waters of San Antonio Creek have alternately flowed into the Santa Ana and San Gabriel rivers; the latter being at one time probably reached by a stream flowing in the wide northern valley, in what is known as Walnut Creek wash. The mechanism by which this alternation is brought about can even now be readily seen when, after a season of unusually high water, cross ridges or kames of bowlders and cobbles are found to have formed directly in the way of the main stream near its exit from the canyon, compelling it to change its line of flow at a considerable angle on its way down the fan, or sometimes dividing it into numerous channels, which themselves may again fork on their way. Several such channels now carry water during winter, and many more now abandoned may be traced by the cobble belts that radiate from the mouth of the canyon. Between these lie areas of finer gravel, sand, and silt, but at the present time very little clay, since the steepness of the slope precludes the existence of any considerable bodies of back water. In the borings, however, irregular deposits of red loam and clay similar to that already mentioned as lying along the valley borders, are con-

[a] The California miner's inch is equal to 0.02 cubic foot per second.

stantly encountered, sometimes of such thickness and uniformity as to indicate that they form part of the original valley deposits. This is especially the case on the upper portion of the slope, including the Martins and Del Monte cienagas, where there appears to be a shelf of the red clay that causes the water to rise comparatively near to the surface in the cienagas and shallow wells; while a short distance below the depths of the wells suddenly increase materially, and in those down the slope only minor sheets of red clay, such as might have been redeposited by the stream in forming its fan, are encountered in the borings. The Fleming tunnel, mentioned below, was probably located just above the edge of this red-clay shelf. It was probably on top of this clay sheet that a steep cone of coarse débris was originally formed at the mouth of the canyon.

Such a cone, as already explained, will remain easily pervious to water down to its oldest portions, even though the fan may subsequently be built up in front of it so as to form a long, gentle slope from near the apex of the cone. From the latter, filled up with water by infiltration at each recurring flood, the water will be forced into the more porous layers, especially into the gravel beds of the old buried channels; and if these happen to be near the surface from the effects of erosion, or are tapped by wells or tunnels driven into the slope, water may burst forth with considerable energy for a time, but will subside and sometimes cease altogether when the pressure column has been considerably lowered by the outflow. Artesian wells bored into such a fan will be more or less variable in their flow, according to the extent of the season's rainfall or the opportunity for absorption that existed at the time of the flood. If from any cause the main current of the stream has been diverted in a different direction, or if the condition of the cobble surface has been altered so as to retard absorption (as may happen even as the result of cultivation), there is likely to be a diminution of flow and sometimes an entire cessation of the water supply, even when pumping is resorted to.

All these variations have been repeatedly observed on the Pomona slope. Thus in 1884, a season of exceptionally high rainfall (40 inches), there was in May an eruption of water within the town site, on Mr. Loop's place, yielding such a volume of water that lands several miles away were irrigated by it; but the flow subsided in the autumn and has not reappeared since, no similarly high rainfall having occurred. During the same season the artesian wells spouted exceptionally large amounts of water, some being, however, much more quickly and extendedly affected than others; and similarly, during the succession of dry seasons which has lately afflicted southern California, most of these wells ceased to flow above the surface and had to be pumped, while others ceased entirely to supply water. It is evident that the pressure column in the débris cone at the mouth of the canyon had sunk so low that it failed to reach a number of the borings any more.

A tunnel driven into the middle slope on Mr. Fleming's place, in 1888–89, developed quite an abundant flow of water, to which several wells on a lower level responded by a diminution of flow. In this tunnel an alternation of red clay and gravel was struck, the latter, of course, yielding the water, and the flow was continuous and steady. Quite different was the result from a tunnel driven high up on the slope within the limits of the central gravel cone. At first there was a very promising flow, and the parties interested were jubilant; but in a short time the flow began to decrease and finally dwindled to mere drippings. The limited portion of the pressure column above the high-lying tunnel had been exhausted, and there remained only a little seepage from the summer flow of San Antonio Creek. A similar and very costly example, described further on, occurred in the Santa Ana gravel cone, near the mouth of the canyon.

It has been noted that the wells in the Palomares Cienaga have fallen off materially in their flow since the time when they were bored, and that they have responded much more slowly and less abundantly to a season of higher rainfall than the wells farther east. An examination of the western portion of the slope shows that, owing doubtless to the lesser slope in that direction, the materials there are finer and less pervious, and the same observation holds true in the record of borings. And since, as already stated, the tendency of the main branches of the San Antonio is now toward an increasing eastward deflection, the probability is that the Palomares Cienaga will become even less productive of water than it is now.

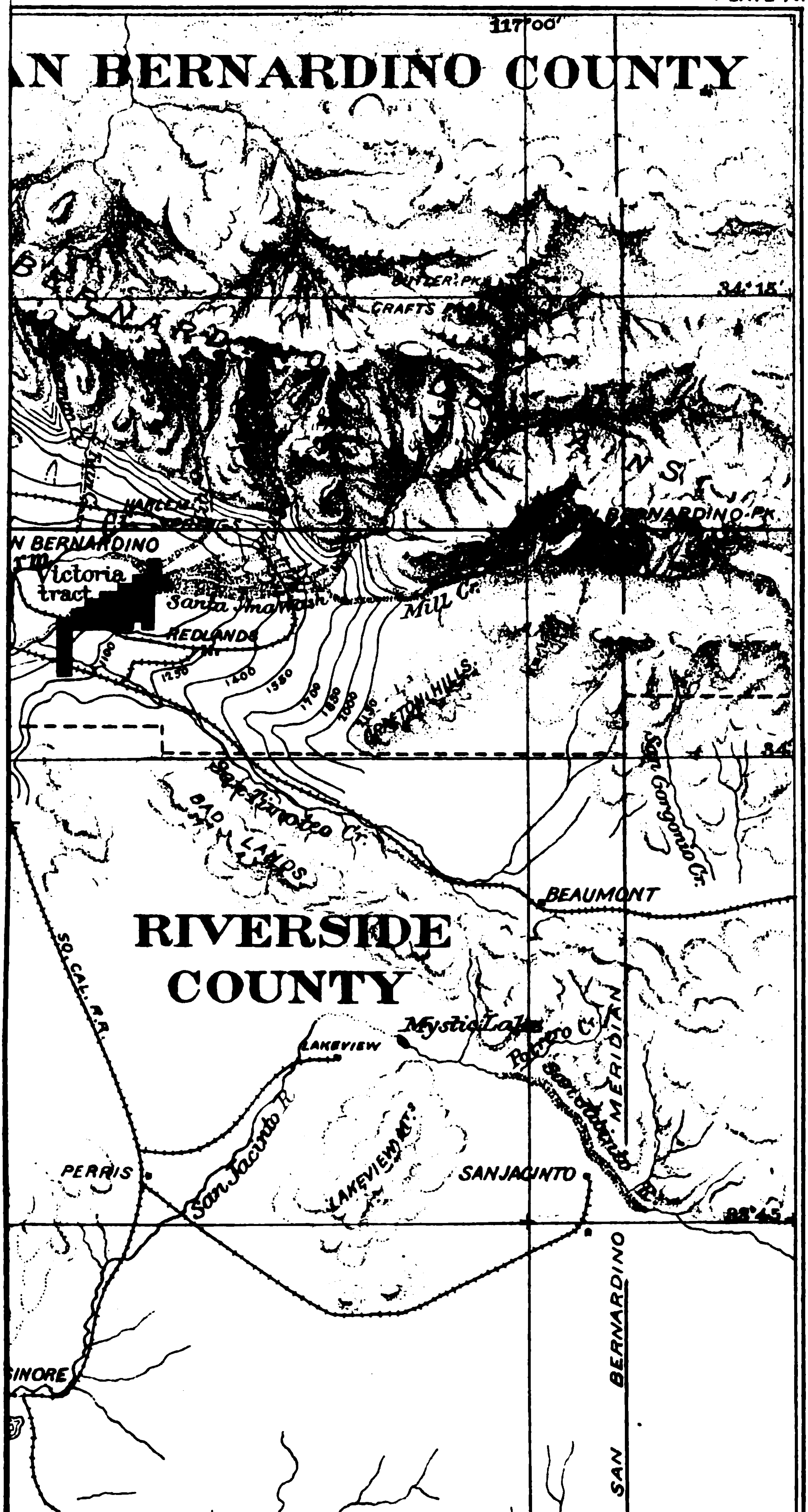
It is not only on the upper part of the San Antonio slope that abundant flows exist in times of normal rainfall. Copious flows have also been obtained from numerous bore holes near its base on the Chino ranch, and although all, or nearly all, of these also have lately had to be pumped, their supply is still good.

As might be expected, the drought years from 1898 to 1901 have made their effect felt in the water supply of San Antonio Creek and débris fan. Not only has the summer flow of the creek fallen at one time as low as 175 inches in place of the 850 inches with which it was credited during the period of abundant rainfall, while numerous bored wells flowed nearly an equal amount, but the greater number of wells have ceased to flow and their water has had to be raised to the surface by pumping, or latterly, by means of an "air lift," which permits a more convenient application of power in the case of bore holes so widely scattered, and partly on private lands. It is hoped that the needful supply for the Pomona and Chino lands will be maintained by extending the pumping system to the wells that have ceased to flow. It appears that the Palomares Cienaga, in which the flow had greatly diminished before the drought set in, is now yielding well by means of the air lift. Many additional wells and additional tunnels have been

excavated in search of water, but in the absence of previous exact measurements of flows, the influence exerted by these new wells upon the old ones can not be accurately stated. The Martins and Del Monte cienagas, in which the water formerly overflowed spontaneously and where bore holes yielded abundant flows, are now utilized only by pumping. In the Pomona Times of March, 1900, a summary is given of water developed from wells existing at the time, aggregating 2,953 inches. It is stated that while some of the wells are likely, according to experience, to diminish their output to the extent of 50 per cent during the seasons of lowest water, the average diminution is estimated at not over 25 per cent, which would make the water supply available at Pomona during summer 2,200 inches, outside of the direct flow of San Antonio Creek.

THE ABSORPTIVE AREA OF THE SAN ANTONIO FAN.

It is not easy to define exactly the limits of the areas within which the flood waters of the San Antonio are usually absorbed into the higher portions of the central débris cone of bowlders, cobble, and coarse gravel. Roughly speaking, it lies within a radial sector of about 2 miles from the mouth of the canyon, materially prolonged, however, in the direction of the present outlets adown the slope, in which the water can be seen gradually disappearing as it descends. A wastage of about 60 inches from the Pomona Water Company's gatehouse near the Indian Mesa, which began in May, 1888, as the result of that season's heavy rainfall, was at first absorbed in the gravel a short distance below, but gradually reached farther to as much as one-half mile in the direction of the Martins Cienaga. The flow from the group of wells located in that tract began to increase slowly in October of the same year and reached a maximum in March following, then gradually decreased to the normal flow. Thus it took the wastage water six months to reach the cienaga 2 miles away, and nine months to produce its maximum effect of over 50 per cent increase. This slow penetration, due to the friction encountered, exerts a most important effect in regulating the water supply so that the effects of a dry season will not be immediately felt by irrigators, while the flood waters of a wet season are stored up in large part for future use. The extent to which this occurs is, of course, dependent first upon the magnitude of the storage mass of débris, and next upon the perviousness of the surface deposits through which the water must penetrate. If by any means that surface becomes clogged, the flood waters will to a much greater extent pass away over it, while if open it must be assumed that the more heavily the previously existing supply has been drawn upon by wells or tunnels, the more readily and abundantly the flood waters will infiltrate into the cobble formation. This is a most important consideration, as human intervention may measurably influ-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117°00'
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Victoria tract
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BEAUMONT
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SO. CAL. R.R.
Mystic Lake
LAKEVIEW
Potrero Cr.
MERIDIAN
San Jacinto R.
LAKEVIEW MTS
PERRIS
SANJACINTO
SAN BERNARDINO
INORE

ence the surface conditions both favorably and unfavorably. If, for instance, the denudation of adjacent slopes in consequence of deforestation should cover the absorbent cobble surface with even a thin layer of earth, the penetration of the water, and with it the extent of the storage, may be materially diminished. It is the impression of the writer that the decrease of flow in the wells of the Palomares Cienaga may in part at least be due to such influences brought to bear on the western slope of the fan.

It will be noted that the typical form and critical location of the San Antonio débris fan renders it of unusual interest from a general point of view, not only with regard to the question of water supply, but also in connection with that of the formation of the broad Cordilleran valley plains, lately discussed by Shaler;[a] for we have here an actual example of fan building clear across the valley, resulting in an important change in the direction of the drainage, and the building up of an alluvial plateau in the upper valley, which will be next considered.

THE SAN BERNARDINO VALLEY.

DRAINAGE SYSTEM OF THE SANTA ANA RIVER.

The Santa Ana River (see map, Pl. X), entering the valley from the north at its northeastern corner, receives its main water supply from the San Bernardino Mountains, of which the peak of that name forms the highest point, sometimes showing snow on its summit until late summer. Its extreme western affluent, Lytle Creek, carries the scanty drainage from the northern and northeastern slopes of Cucamonga, San Antonio, and Bald mountains alongside the Cajon Pass. Above the mouth of its canyon the Santa Ana is a wild mountain torrent, which in times of flood carries before it enormous blocks of rock (Pl. XI, fig. 1), the concussions of which are sometimes heard miles away, resembling the distant discharge of artillery. These bowlders form in front of the canyon mouth a difficultly penetrable wilderness of stones of all sizes. Large masses of cobbles and shingle are, however, carried beyond this barrier and form extensive areas of bare gravel surface outside of the canyon mouth.

Two miles away to the south, and perhaps 250 feet higher up, the head of the valley is entered from the east by Mill Creek, which drains the southern slopes of the group of mountains of which San Bernardino Peak is the highest. Like Santa Ana River, Mill Creek is a mountain torrent, and in times of high water carries large quantities of bowlders of less size than those carried by the Santa Ana but associated apparently with an even larger proportion of cobbles, shingle, and gravel. The deposits formed by these join those derived from the Santa Ana

[a] See Bulletin Geological Society of America, vol. 12, pp. 271-300: Broad Valleys of the Cordilleras, by N. S. Shaler.

a short distance from the mouths of both canyons, so that the two form one extensive detrital mass (Pl. XI, fig. 2) extending southwestward from the northeast angle of the valley. Mill Creek, issuing from its canyon at a considerably higher elevation than the Santa Ana, has at various times excavated deep channels into the detrital beds, affording excellent profiles illustrating the structure of the latter. Here we observe numerous alternations of irregular beds of cobble and shingle with sand and loamy materials, the latter often almost water-tight and necessarily shedding the water that may have infiltrated into the coarse materials above at any points where they emerge at the surface or are overlaid by pervious beds. Accordingly we frequently see tricklings or springs along the sides of the eroded channels, evidently representing the reissuing of creek water filtered into the cobble beds higher up, into which channels filled during high stages of water lose their flow at short distances from the main stream. The channel of the main stream, however, is almost impervious from fine matter deposited by the summer flow.

Still another stream debouches into the San Bernardino Valley at its head. At the southeast angle San Timoteo Creek issues from the canyon of the same name that leads up to the San Gorgonio Pass, the route of the Southern Pacific Railroad. But this stream carries such a small volume of water even at flood time that its alluvial deposits, mostly of a sandy and loamy nature, are quite limited, and as it does not head in any high range its summer flow is insignificant. Hence it does not to any noticeable extent influence or modify the phenomena connected with the drainage of Santa Ana River and Mill Creek.

No streams of practical consequence enter the valley from the south side for the 20 miles between the San Timoteo and Temescal creek, to be considered later. On the north side of the valley Plunge, City, and Lytle creeks, with a number of minor streams, come down from the Sierra Madre and yield locally important supplies of irrigation water; and the small débris fans formed near their exits from the canyons have been tunneled for the water which, save in time of flood, is rarely seen far down in the sandy "washes" through which they may enter the main stream. Lytle Creek flows at the eastern foot of an abrupt ridge extending down from the Cajon Pass, which terminates on the west what is known as the upper valley, some 15 miles from its head, at Redlands, and a mile west of the town of San Bernardino. This ridge is composed of the same sandy and gravelly deposits, at times consolidated into hardpan, which underlie the sandy plateau on which Colton and Rialto are situated, some 80 feet above the bed of the Santa Ana River adjacent. This ridge has been popularly credited with being a "dike confining the subterranean waters, and thus causing the artesian rise in the valley above;" but this supposition is wholly groundless. At its foot, bordering Lytle Creek for a short

Fig. 1.

Fig. 2.

VIEWS OF SANTA ANA CANYON.

distance, is a tract of very rich black clay or adobe land, evidencing the former existence of a swamp. It contrasts sharply with the sandy loam elsewhere characterizing the alluvial plain of the Santa Ana River, and is in fact a cienaga, upon which pools of water sometimes remain late in the season.

WARM CREEK.

The most considerable stream within this upper valley is Warm Creek, which rises in the valley itself at Harlem Springs, not far from Highlands. It has no connection whatever with the surface drainage of the Sierra Madre slopes, which are 1½ miles away. Its water is derived from a number of springs, or rather seepage flows, breaking out for some distance at from 3 to 5 feet beneath the surface, apparently "without any just cause or provocation," and uniting to form a lively stream whose volume varies little from winter to summer, its minimum flow in ordinary summers being about 2,000 inches. It forms the supply for the old Riverside Ditch, being flumed across the Santa Ana River on a high trestle.

It is impossible to interpret the origin of Warm Creek in the open valley otherwise than as an outbreak of subterranean waters under pressure; and the only possible source which the conformation of the valley permits to be considered is the great débris fan of the two streams above, the Santa Ana and Mill Creek, already described. But if this is the true source, there ought to be other manifestations of such water pressure, and these would naturally be sought in the lowest portion of the valley, in or near the channel of the Santa Ana River itself.

THE VICTORIA CIENAGA.

The exact counterpart of the Harlem Springs is in fact found in the bed of the Santa Ana River, about 3 miles east of the town of San Bernardino. Here, as observed by the writer in May, 1889, for a distance of over 2 miles the main stream of the river is joined by numerous springs and streamlets largely originating at or near the foot of the bluff banks, mostly in ill-defined but copious seepages, but sometimes in lively, single, bubbling springs, evidently coming from some depth under pressure. One of the streamlets thus flowing from the bed itself measured at the time fully 75 inches of water, and the total addition thus made to the volume of the main stream was very obvious and considerable. Another valley stream, Parrish Ditch, coming from the north, outside of the river bed, carried not less than 157 inches.

Lower down on the river, also, continual accessions from springs and seepages within the bed are received, so that its volume keeps constantly increasing. Immediately opposite to the town of Riverside 400

to 500 inches of water rise from the margin of the channel within a short distance in the form of springs, and form an important source of irrigation water. Still below, and to where it enters the lower canyon through the Santa Ana range, the river continues to gather water to the extent of several thousand inches, most of which passes through the canyon and supplies irrigation water to the towns of Anaheim, Orange, and others.

It has been supposed that this water is at least partly due to irrigation above; but an examination of the facts in the case does not sustain this supposition to any considerable extent. In the absence of any noteworthy tributary on this portion of the river's course, Warm Creek having been completely taken up by the Riverside irrigation companies, there is no other explanation possible than the rise of water from subterranean sources, just such as was observed by the writer in 1889 on and above the Victoria Cienaga.

In addition to these evidences of a copious subterranean water supply from a high level, there are several natural "artesian springs," among them Hunts Spring, situated out in the open plain, which flowed a very considerable stream, rising with such force as to form a water dome above the surface of the pool around it.

ARTESIAN WELLS.

It was natural that these evidences of subterranean water pressure should lead to the boring of wells to increase the supply, and this was done most successfully by the original owner of the Victoria Cienaga, Mr. Matthew Gage, who gave it the name. Since the observations made on these borings are by far the most complete extant in the valley, and were in large part made by the writer personally in 1889, they are here given somewhat fully as a basis for comparison with changes that have taken place since that time.

In the borings made in the water tract there was usually penetrated from 20 to 50 (sometimes as much as 80) feet of alluvial soil and sand, the latter gradually increasing in coarseness downward and bearing more and more and larger gravel, until at the depth of 90 to 100 feet the material was largely cobbles of considerable size, rendering boring very difficult, and at times, when a vigorous supply of water was struck, resulting in the forcible ejection of stones almost filling a 7-inch pipe. It being very difficult to reach any considerable depth with a pipe of so small a diameter, the 10-inch bore hole has been adopted as the regular size on these lands. It has been noticed that the size of the cobbles decreases toward the sides of the valley, where greater depths are easily reached, while here 211 feet was then the greatest depth attained with a 10-inch bore, and most of the good wells ranged from about 140 feet to greater depths.

The interspaces between the cobbles are everywhere found filled with

sand and gravel, and the water-bearing gravel beds alternate with more or less impervious beds of clayey material or hardpan at intervals varying from a few to 15 and more feet. As each additional layer of impervious material is penetrated by the auger, the rise of water is more energetic and copious. But the beds of gravel and cobble continue to the lowest depth reached; and, according to the usual rule, they probably fill the depths of the valley to the bed rock. How deep this may be we can but conjecture from the steepness of the granite slopes that form the sides of the valley, and from the fact that a bore hole situated not far from the mouth of the San Timoteo Canyon, in the southeast corner of the valley, where the Southern Pacific Railroad ascends to the Gorgonio Pass, the depth of 850 feet was reached while the auger was still bringing up the sandy and gravelly clay characterizing that canyon in contrast to the streams entering the valley from the north and northeast, which discharge mainly cobbles, gravel, and sand.

The nature of the deposits filling the central part of the valley is well illustrated by the subjoined record of the deepest well sunk thus far in the Victoria tract, which, with others, has been communicated by the Riverside Trust Company, the present owners of the land:

Record of well No. 4, new series.

[The flow of this well was 75 miner's inches.]

Material.	Thickness.	Material.	Thickness.
	Feet.		*Feet.*
Clay [a]	80	Fine, coarse sand	32
Sand, gravel	8	Hard clay	30
Clay	6	Fine sand	4
Fine sand, gravel	4	Hard clay	12
Clay	12	Fine sand, gravel	8
Sand, gravel	18	Sand, gravel, rocks	26
Clay	6	Gravel, rocks	4
Sand, gravel	32	Finer gravel	6
Gravel, rocks	118	Hardpan, gravel, cement	6
Clay	10	Fine sand, fine gravel [b]	10
Fine sand	4	Coarser gravel, sand [b]	4
Clay	12	Coarse sand, gravel, rocks [b]	8
Fine sand, gravel [b]	34	Sand, gravel, rocks	14
Clay	4	Finer gravel, fine sand [b]	12
Fine sand, gravel	14	Fine sand, gravel [b]	10
Clay	10	Coarser gravel [b]	4
Fine sand	2	Sand, gravel, rocks [b]	6
Clay	4	Sand, gravel, rocks	6
Fine sand, gravel	10	Sand, finer gravel	4
Clay	4	Clay	4
Fine sand, gravel [b]	4	Very fine sand	2
Clay	80	Clay	4
Fine sand	2	Sand, gravel [b]	8
Clay	6	Sand, gravel, rock	7
Fine sand, fine gravel [b]	6		
Hard clay	4	Total depth	675

[a] The "clay" so frequently recorded is in most cases simply a loam, mostly quite sandy, but becoming plastic by the working of the auger.
[b] Water.

The increasing coarseness of the materials with greater depth is very strikingly shown in this record, and parallel with it runs the increase of water-bearing levels and increased flow of water. The static pressure increases materially with the depth as well when the bore hole enters these lower cobble beds, which may be presumed to be in more

direct communication with the cone of coarse materials at the canyon mouth than are the higher strata which have been deposited under conditions that tend to cause the main stream to meander in the finer materials deposited on a gentler slope. At the same time, if the flow were correspondingly great these deeper wells would also be most liable to cause a serious diminution of the pressure column which feeds the wells of the valley generally.

At the time the writer first investigated the subject (1889) there had been bored in this tract, within a distance of about 1¼ miles, 27 wells, yielding a measured aggregate of 1,091 miner's inches. Within the distance mentioned there is from the center of the highest group of wells to that of the lowest a fall of about 31 feet.

In order to discuss intelligently the tests made regarding the flow of these wells, it should be understood that they are located in four groups, numbered from A to D, upstream. (Fig. 4.) In the first attempt to

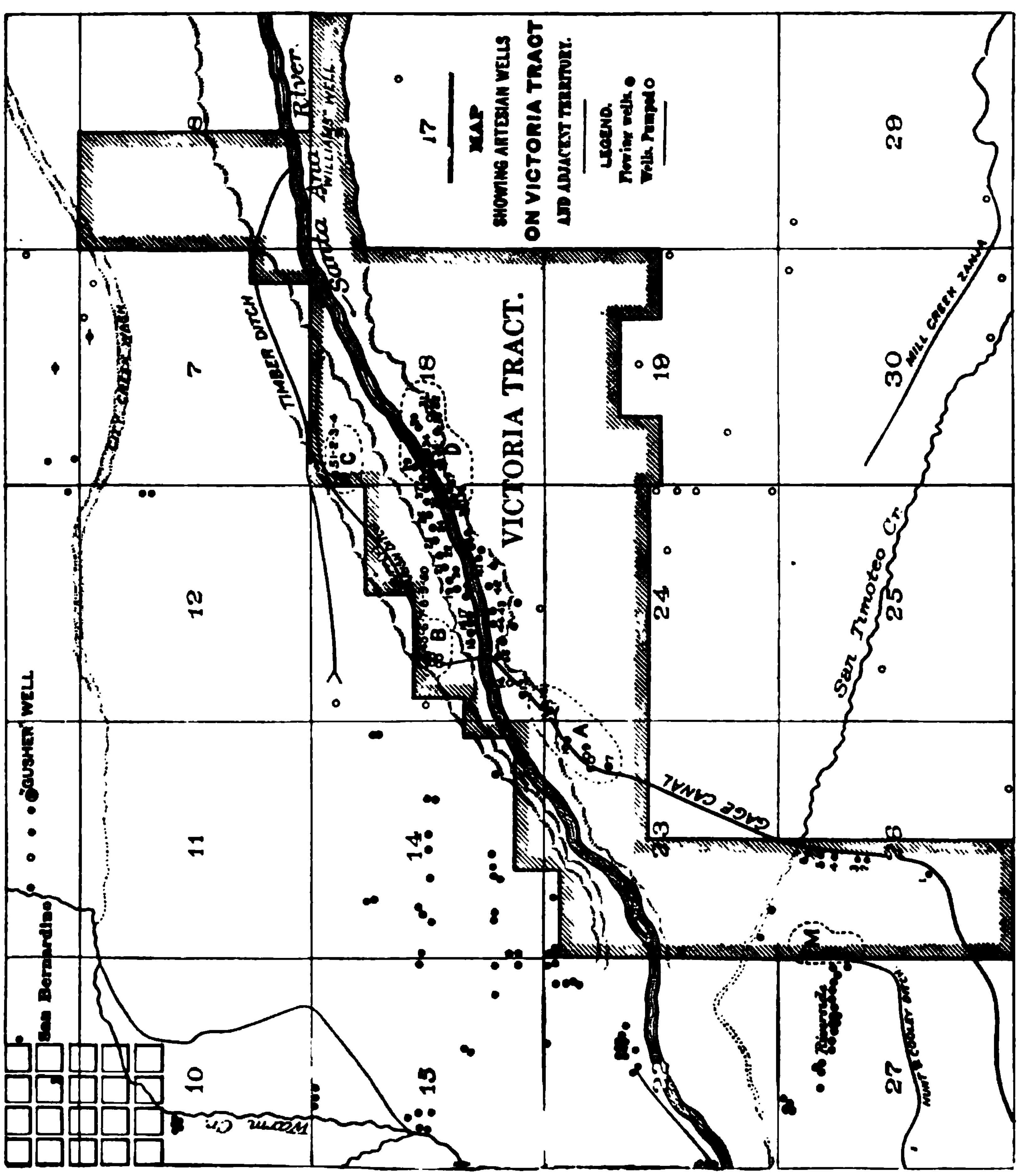


FIG. 4.—Map of Victoria tract.

sink wells of 7-inch diameter, four such (Group C) were sunk quite near together and to an average depth of only 110 feet, progress being stopped by large cobbles. These bore holes yielded an aggregate of only 35 miner's inches of water. Groups A and B, of six bore holes each, differ in that in all the wells of Group B, and in two of the wells of Group A 7-inch pipe was used. In four of Group A 10-inch pipe was used. Group A yielded 260 miner's inches, and Group B 225 miner's inches, yet in Group B the distances between the several bore holes ranged only from 15 to 50 feet, and Group A from 67 to 722 feet, indicating that the proximity of the holes influenced the flow but little. Group D, of eleven wells, 10 inches in diameter, and from 42 to nearly 700 feet apart, gives an aggregate of 571 miner's inches, therefore not widely out of range of the assumption that the output is nearly in proportion to the number of bore holes.

By way of showing the collocation of these groups of wells, the following summary of the data relating to Group D is given:

This group consists of 11 wells, all with 10-inch pipe, and ranging in depth from 110 to 160 feet. Nine are located on the south side and mostly quite near to the river bed; two are near the north bank, one being in the present bed. The distance between the centers of groups A and D is about 5,800 feet; between D and B, 2,400 feet. The average elevation of Group D above Group B is about 18 feet, and above group A, 31 feet.

The following table gives the distances between wells and the discharge of each well in Group D:

Distances between wells in Group D and their discharges.

No. of well.	Distance from well next above.	Water discharge.	No. of well.	Distance from well next above.	Water discharge.	No. of well.	Distance from well next above.	Water discharge.
	Feet.	*Miner's inches.*		*Feet.*	*Miner's inches.*		*Feet.*	*Miner's inches.*
38	00	51	34	139	82	30	440	87
37	80	51	33	566	65	29	860	56
36	687	43	32	315	35	28	300	74
35	117	55	31	42	22			
						Total		571

All the measurements above recorded show the condition of the wells about thirty-six hours after all had been uncapped and had been running their full streams. This point is of some importance, because measurements made immediately or soon after uncapping a well that has remained closed for some time show at first a considerably larger discharge, evidently due to accumulated pressure, or what might be called a "local head," requiring some time to run down to the normal discharge.

DEGREE OF INTERDEPENDENCE OF WELLS.

The extent to which the discharge of any well or group of wells is influenced by that of others situated at greater or less distances being

a question of great practical interest, since upon the answer depends the aggregate amount of water to be expected from further development by the boring of additional wells, the point was tested in a variety of ways, the more important being the following:

Well No. 50 in Group B had for some time remained capped, with an inch pipe carrying the water supply to a dwelling house some 300 yards away, the water reaching the level of 20.5 feet above the casing when all the other wells of the group were capped. It was found that when all the other wells of the group were uncapped the water level at the house fell about 3 feet 7 inches. As stated above, the total flow of the wells of this group was 225 miner's inches, that of No. 50, 20 inches. It is distant only 40 feet from the well No. 49, having a flow of 63 inches, and all the rest of the group lie within 130 feet. Yet the measurement showed that the opening or shutting down of the flow of 205 inches, or ten times the amount of the flow of well No. 50, influenced it only to the extent of not quite 18 per cent, or 1¾ per cent of the total flow concerned.

Well No. 37 of Group D had been steadily running for more than a year, all the rest of the group, as well as groups B and C, being closed. It was discharging about 61 inches. After nine other wells, Nos. 28 to 36, inclusive, had been uncapped, No. 37 was found to have decreased to 57 inches in the course of about three hours. On opening No. 38 within 80 feet of No. 37, the flow of No. 37 suddenly fell to 55 inches, and forty-eight hours afterwards it had reached its minimum flow of 48.4 inches; which, however, five hours after was found to have risen again to 51 inches, the figure adopted in the table above. Such fluctuations of a few inches appeared in measurements made at different times of the day in almost all cases of strong flow, possibly as the result of barometric variations or other diurnal causes. It will be seen that in the case of this well the letting loose of 520 inches of water within an area of 17 acres surrounding it caused a decrease of the flow it had been running by itself of only 10 inches, being about one-sixth, or 17 per cent, of its own flow when all were closed and 1¾ per cent of the total discharge of the group. This result agrees very closely with that obtained in the case of well No. 50 of Group B, reported above.

After all the wells had reached a state of constant discharge, the 606 inches of groups C and D were shut off at about 5 p. m. in order to observe the effects on the other groups. Group B was measured at 10 p. m. and was found to be discharging 211 inches. Six hours before, when all the other wells were still open, the discharge was 205 inches, showing a difference of 6 inches, apparently caused by the shutting down of the aggregate of 606 inches at a distance averaging a mile. This is a very slight effect, at best, being less than 3 per cent of the total discharge of Group B, and only three-fourths per cent of

the total discharge concerned. But the fact that on the morning of the same day the discharge of Group B was found to be 215 inches renders it doubtful that even the effect observed was directly due to the shutting down of groups C and D. Unfortunately, time did not permit of the continuation of the observations so as to settle this point definitely.

From 1889 to 1892 twenty-eight wells were bored on the Victoria tract in addition to the twenty-seven existing in 1889; and in 1892 a full and systematic measurement of all the fifty-five wells was made by the engineers of the Riverside Trust Company, in order to ascertain the effect, if any, of the boring of the additional wells upon the flow of the first twenty-seven. The method pursued was to ascertain, first, the flow of each individual well when all the rest were closed. Finally, each well was remeasured while all were open, so as to enable a full comparison to be made between the sum of the flows of all the wells running one at a time and that of the entire series of fifty-five when flowing simultaneously. In addition, each well was remeasured as additional ones were opened, so as to give room for comparison of individual differences in their mutual influence. This comparison proved, indeed, a great irregularity in that influence, not at all proportional to the relative amounts of flow. For the purposes of this paper, however, it will suffice to give the figures showing the aggregate of the flows when each well flowed alone, and to compare it with the aggregate flow when all the wells were opened simultaneously. It should be noted that the measurements were made in October and November, 1892, therefore after the first season of deficient rainfall and at the time of minimum flow of all the streams.

It was found that while the sum of the flows of the wells when each was measured singly with all the others closed gave 3,709 inches, when all were open the total flow was only 1,793.5 inches, a difference of 1,915.5 inches, or about 52 per cent. Considering that in the measurements made in 1889 the maximum difference observed on any one of the twenty-seven wells when flowing alone and with all others open was only 18 per cent, this result was quite unexpected, on any probable basis of calculation.[a]

It is noteworthy that when all the wells of the system were closed the water rose to the surface on the lands adjacent to the river and stood in pools above the level of the bed of the running stream, showing the subterranean origin of the water of both stream and wells to be clearly common. It was also worthy of note that when all the wells were closed except one, No. 35, near the head gate, the latter's static head was 35 feet, while when all were open the head was 24.34 feet,

[a] A careful study of the details of the measurements made in 1889 and in 1892 will show that the methods used differed so widely that the results obtained can be compared only in the most general way.—Ed.

or 10.66 feet less than before. This is a reduction of less than one-third, while, as will be remembered, the total reduction in the flow of wells under similar conditions was over 50 per cent.

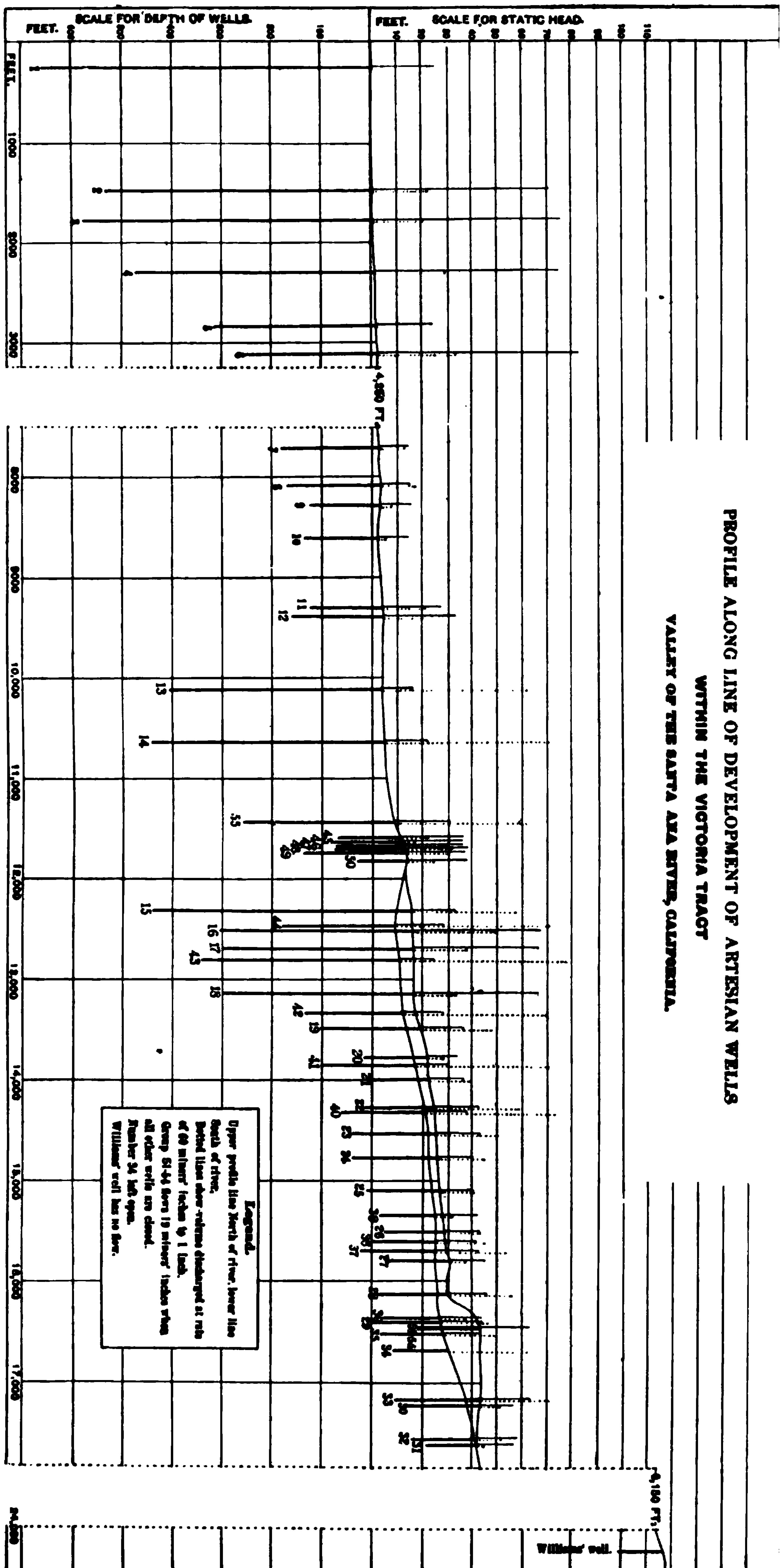
When we compare the details of measurements made in 1892 with those of 1889, we find that while the twenty-seven old wells in the latter year were found to discharge 1,091 inches, in 1892 their aggregate flow was only 512.3 inches, a decrease of 53 per cent, which agrees nearly with the percentage of the general decrease deduced from a comparison of the aggregate flows of the wells open singly, and all open simultaneously, as above quoted.

In order to determine to what extent outside causes, independent of the boring of additional wells on the Victoria tract, had influenced the product of the wells as found in 1892, all the new wells were closed, so as to allow only the twenty-seven old wells to flow. Their total yield was then 820.34 inches, a decrease of 270.66 inches, or 24.8 per cent, from their flow in 1889. This decrease was, then, obviously due to some general cause.

For a better understanding of all the data of the problem it is important to note that at that time, the driest portion of the year 1892, the Santa Ana River at the head gate of the Gage Canal system had a total flow of about 450 inches, all of which originated in seepages and springs situated within the limits of the tract, in the bed or "wash" of the Santa Ana. At the same time the Riverside Canal, deriving its water mainly from Warm Creek, was carrying about 3,100 inches of water. Lytle Creek was discharging more or less waste water (surplus over that used in irrigation) into Warm Creek.

The results of these measurements are shown graphically in the accompanying profile (Pl. XII), in which it must be understood that the base line of the several data given is the ground surface along the Santa Ana River, on which the elevation of each well above sea level may be read off by means of the coordinate lines. Below the ground surface line the depth of each well is indicated by the length of the solid line, on a scale of 200 feet per linear inch. The corresponding solid lines above the ground surface indicate the static head (the height to which the water will rise in the standpipe) in each case, on a scale of 40 feet per linear inch, while the dotted lines indicate the corresponding flows as measured, expressed in miner's inches on a scale of 60 miner's inches per linear inch on the diagram. This diversity of scales, while apparently complex, serves to render apparent at a glance the correlations between the four classes of data platted, and their discussion leads to several unexpected conclusions.

The most obvious one is perhaps that, taken all in all, the shallow wells have both a low static pressure and a scanty flow. This is in accord with the general opinion, and yet when we consider the individual cases comparatively we find that considerable difference in depth sometimes causes but a slight difference in flow. Compare in



PROFILE ALONG LINE OF DEVELOPMENT OF ARTESIAN WELLS
WITHIN THE VICTORIA TRACT
VALLEY OF THE SANTA ANA RIVER, CALIFORNIA.

this respect well No. 15 with well No. 22, also with Nos. 55 and 41, although the results in the latter case are less striking. This is easily explained on the ground that despite a higher pressure column behind it, the deeper well may not communicate with it as freely through fine materials as when in the case of a shallow well, coarse cobble or gravel alone intervenes between the bore hole and the lower pressure column.

A more unexpected though more easily explained fact is that shown conspicuously in a number of cases of the utter lack of correlation between the static pressure on the one hand and the quantity of flow on the other. This is most conspicuously shown in the deeper wells, where in the case of Nos. 1 to 5, as also in that of Nos. 16, 17, and 18, a very high static pressure is accompanied by a relatively light flow. Conversely, in the case of wells Nos. 40, 41, 42, 43, 44, 55, 14, and 13 a very large flow accompanies the very low static pressure. This is altogether contrary to what is commonly observed in the artesian basins properly so called. Both anomalies, however, are readily explained by the variation in the structure of a débris fan, as set forth in the first portion of this bulletin. For when fine-grained materials intervene between the pressure column and the bore hole, no very active flow can occur, even though the pressure be high, on account of the heavy friction encountered by the moving water. On the other hand, where intervening materials are open, such as coarse gravel or cobbles, the water can move freely, and this very motion, according to well-known laws of hydraulics, will prevent the manifestation of the full static pressure that may be behind the flow. It is in such cases as these especially that wells lying on a higher level may be seriously depleted by bore holes sunk farther down into the same ground belt, while when the static pressure is high, relative to the flow, the reverse will usually be true, and the higher lying well will be more likely to secure the best flow. It should be noted that according to the company's records the wells Nos. 41 to 44, inclusive, have proven to be the very best of the whole 55, both as to original product and permanency of discharge up to the present time. No. 41 actually is discharging more to-day than when excavated in 1892. This testimony in favor of free-flowing wells with low static pressure is important to bear in mind in the development of water from débris masses.

The question of the extent to which the boring of wells lower down in the valley may affect the flow of those above is, therefore, not a simple one, as would be the case in an artesian reservoir having a static, direct-acting water level. The accumulation of pressure when the bore holes are closed, mentioned above as the "local head," even in the case of bore holes closely contiguous, proves that the friction impeding the flow is so great that neither the laws of static pressure nor those governing a confined but free-flowing water column under pressure, can be applied in this case. The principle is forcibly illustrated by the fact, shown above, that the bore holes showing the highest

static head are by no means always those giving the strongest flows. It follows that under such conditions a well located higher up on the water slope may intercept and partially deplete the flow of one situated lower down, and as the deposits in the débris fan are not uniform it is impossible to predict just what will happen to any particular well or group of wells as the result of the boring of others either lower down or higher up on the slope. It can only be predicted that a great increase in the number of bore holes dependent upon the water stored in the débris fan will in the course of time exert a material effect upon the flows by the reduction of the pressure column behind all these.

Such a reduction of the pressure column may, however, be at least partially offset in times of normal rainfall by the absorption of a large proportion of flood waters, resulting from decreased frictional resistance to percolation. To some extent, therefore, an increased demand may be expected under normal conditions to be met by an increased supply. It thus seems that such self-regulating reservoirs as these gravel masses, free as they are from loss by evaporation, can not easily be excelled in utility by costly artificial structures so long as the freely absorbing area around the mouths of the canyons is maintained.

POSSIBLE PRODUCTION OF WATER FROM A GIVEN AREA.

There is, of course, in every artesian basin or storage mass an ultimate limit beyond which the further multiplication of bore holes fails to add to the total discharge; while short of this limit each additional bore hole, while depleting somewhat the flow of those previously bored, will yield a certain additional supply, which may or may not justify the cost of boring. This being understood, it is nevertheless of interest to estimate, on the basis of the facts recorded above, the possible product of an area advantageously situated in the trough of the valley, as is evidently the case with the Victoria Cienaga, judging from the large size of the bowlders and cobbles found in the borings. For such an estimate Group D can most fairly serve as a basis, as it contains the largest number of wells, most uniformly distributed, and all of the same diameter of 10 inches.

In this group the extreme dimension of the rectangular area obtained by multiplying together the greatest longitudinal and lateral distances of any of the eleven wells is 1,900 by 400 feet, equal to about 17 acres. If we increase these dimensions by adding to each one-half of the average distance between the wells of the group—that is, 168 feet—the area that on ample allowance may be considered as occupied by these wells would become about 27 acres, or 2.46 acres to each one, averaging 54.6 inches of water. At this rate we obtain for the total possible product of the entire tract of 540 acres 11,420 inches of water. A similar calculation applied to Group A, with its 6 wells, leads to a result not widely different from the above, viz, 10,660

Fig. 1.

ARTESIAN WELLS.

Fig. 2.

inches. Taking as a basis the average between the two totals calculated, 11,040 inches, together with the average flow of each of the 17 wells under discussion, 49 inches, the above amount of water would be obtainable from 227 wells bored on the water tract if the pressure column were to remain substantially unimpaired thereby. If we make an allowance in view of the maximum influence actually found in 1889, 17 per cent, calling it one-fifth, we obtain 8,830 inches as a possible net result.

When it is considered that the experiments made in 1889 failed to show unequivocal evidence of any influence of the several groups upon each other, and that in the case of well No. 37 of Group D the joint influence of two neighboring wells within an area of 27 acres when in full flow amounted to only 17 per cent, or $1\frac{3}{4}$ per cent of the total discharge of the group; and when it is further considered that the deepest well then bored on the water tract in question had reached only 211 feet out of the great depths still remaining untapped, it seemed that the above calculation did not wildly exaggerate the possible water yield unless the rainfall should fail, or until bore holes elsewhere in the valley should have been greatly multiplied.

In this connection it should not be forgotten that the water power from high-lying wells may be made available for raising to higher ground either the water from wells not having a sufficient rise, or that derived from surface ditches, or even the river itself. Thus, in case of the water tract specially examined, the 571 inches emerging from Group D at an elevation of nearly 28 feet above the head gate of the canal might be very effectively used in pumping water from low-lying sumps in the river bottom up to an available level.

DECREASE OF THE WATER SUPPLY SINCE 1892.

From the year 1892 to 1900 a gradual decrease of the water supply has been noted, not only on the Victoria tract, but throughout the San Bernardino Valley, including both artesian and surface waters. The salient facts of the general decrease are summarily shown in the subjoined table from data in the records of the Gage Canal system, which agree fully with those observed, but not accurately measured, elsewhere in the valley:

Decrease of water supply from sources measured in 1889 to the season of 1899–1900.

Source.	1889.	1892.	1898.	1900.
	Miner's inches.	*Miner's inches.*	*Miner's inches.*	*Miner's inches.*
Group A	260	87.62	32	0.25
Group B	225	120.33	27.50	....
Group C	35	....	....	....
Group D	571	301.35	175	100
Parrish Ditch	157	20	....	....
South Stream[a]	75	....	....	....
Santa Ana River	450	450	15	10
Total	1,773	979.30	249.50	110.25

[a] In bed of river at foot of south bluff.

It will be noted that the reduction of water flow from the old sources, as shown in this table, has been so sweeping that, unless additional supplies could have been developed, the consequences for the lands under irrigation from the Gage system must have been most serious. The deficiency has been avoided by the boring of additional wells of greater depth (the record of one of which is given on page 115) and furnishing abundant flows. Even these, however, have already shown a gradual decrease in their yield. The cause of this decrease might be looked for in one or both of two factors, viz, the rainfall, and the rapid increase of wells all over the valley.

RAINFALL.

As already stated, the first observations on the Gage water system, above recorded, were made in the spring of the year 1889. The season 1888–89 was preceded and followed by several years of rainfall above the average; but after 1892–93 seasons of deficient rainfall began to alternate with seasons of normal rainfall, and finally, beginning with the season 1897–98, there came a series of dry years, which caused widespread distress among irrigators. The following table of rainfall for twenty-one seasons at three principal points of the valley of southern California, viz, Los Angeles, San Bernardino, and Riverside, as given by the United States Weather Bureau, illustrate these facts:

Seasonal rainfall for twenty-one years at Los Angeles, San Bernardino, and Riverside.

Season.	Los Angeles.	San Bernardino.	Riverside.
	Inches.	*Inches.*	*Inches.*
1880-81	13.13	13.50	5.26
1881-82	10.40	11.54	6.31
1882-83	12.11	9.17	2.94
1883-84	38.13	37.51	22.74
1884-85	9.12	10.81	8.97
1885-86	22.31	21.83	9.42
1886-87	14.05	14.50	5.92
1887-88	13.87	17.76	11.76
1888-89	19.28	20.97	15.55
1889-90	34.83	25.45	18.21
1890-91	13.36	18.08	12.89
1891-92	11.85	14.35	6.44
1892-93	26.28	19.82	12.46
1893-94	6.73	8.13	7.12
1894-95	16.11	20.98	16.39
1895-96	8.51	8.11	7.51
1896-97	16.86	16.74	12.85
1897-98	7.06	8.24	5.50
1898-99	5.53	7.49	4.82
1899-1900	7.90	8.64	6.89
1900-1901	10.38	17.29	8.74
Average	15.13	15.76	9.94

It will be seen that while a period of general high rainfall extended from 1883-84 to 1892–93, there was a marked decrease thenceforward, with a minimum in 1898–99. The well measurements made in 1889 may therefore be considered as representing a probable maximum of flow, while the years following the minimum rainfall may reasonably

be expected to show a minimum so far as the effects of the rainfall alone are concerned. In the study of the effects of the rainfall the best records available are again those of the wells bored in the Victoria water tract on the Santa Ana River, which in 1890 was enlarged by additional purchase of land so as to extend for 4¼ miles along the river's course, or nearly 4 miles due east and west, thus reaching near its eastern border the limits of the usual summer flow in the river channel. For this discussion, it seems best to use the data from observations made at the town of San Bernardino, which lies in the open valley and closest to the mountains from which the water supply is derived, and from which locality twenty years' observations are available. The observations made during the same period at Riverside show variations manifestly due to local causes, and while in general trend following the San Bernardino data they are much less regular. The observations made at Redlands from 1888 on agree very closely with those at San Bernardino, but lack the important period from 1880 to 1883. The averages for the twenty-one year period at San Bernardino and Riverside, and of the twelve-year period at Redlands, are as follows:

	Inches.
San Bernardino	15.76
Redlands	15.50
Riverside	9.94

Of these records, that of Redlands is perhaps somewhat too low, because of the lack of the previous seasons' records. Assuming the rainfall during those years to have been the same as that at San Bernardino, the average for Redlands for twenty-one years would become 16.18 inches. Grouping the years in the San Bernardino record with respect to the general average of 15.76 inches given above, we find the following data as averages of the respective periods:

	Inches.
1880–81 to 1882–83	11.40
1883–84 to 1892–93	20.10
1893–94 to 1896–97	13.49
1897–98 to 1899–1900	8.12

Stated in words, this record means that after three years or possibly more of deficient rainfall, ending with the season of 1882–83, there were ten seasons of excessive rainfall, only three seasons being below the general average, ending with the season of 1892–93, and showing an average of 20.1 inches. There then came two years of high or normal rainfall alternating with two deficient ones, averaging 13.49 inches in the four years. Then there followed three years of great deficiency, felt all over the State, including the seasons from 1897–98 to 1900. The season of 1900–1901 was in southern California but little above the twenty years' average; hence quite inadequate to make up for the

deficiency during the three previous years, thus leaving the stress of scarcity of irrigation water unrelieved.

It can not, of course, be doubted that so material a reduction of rainfall during seven consecutive years, amounting to nearly one-half of the normal in the end, should materially influence the artesian supply held in the alluvial fans of Mill Creek and Santa Ana River. But apart from this direct influence there came in another factor of depletion, viz, the boring of a large number of wells all over the valley in order to increase the failing supply of both rain and irrigation water. The number of wells so bored above the sources (springs and seepages) from which Warm Creek and Santa Ana River derived their main flows are comparatively few in number, yet the decrease in the flow of these streams has been very notable, especially in the upper reaches of the Santa Ana, on the Victoria tract, where the once copious flow of 450 inches has almost wholly disappeared, being reduced to 10 inches in 1900.

DEPLETION RESULTING FROM THE MULTIPLICATION OF ARTESIAN WELLS.

The effect produced upon the original wells of the Gage system by additional borings has already been discussed, and it has been shown that within the limits of the Victoria tract the depletion consequent upon the approximate doubling of the number of bore holes was over 50 per cent. It remains to be seen how far the rapid increase of bore holes elsewhere in the valley may have had a share in the general decrease, and whether all these outlets combined take more water out of the general reserve in the Santa Ana-Mill Creek débris fan than the flood waters of these streams are likely to replenish, under normal rainfall conditions, by percolation into the bowlder, cobble, and gravel beds forming the portion nearest the mouths of the canyons. For probably no one expects that the period of deficient rainfall is likely to continue much longer; on the contrary, it seems likely that the general average will be made up by a period of precipitation above the average, as was the case after the drought years of the early eighties.

It will be remembered that at the measurements of the 55 wells existing on the Victoria tract in 1892 it was found that when all but the original 27 bore holes were closed the aggregate flow of the latter was found to have diminished, as compared with the flow measured in 1889, to the extent of 271 inches, or nearly one-fourth, 24.84 per cent. This had happened within the periods of high rainfall,[a] which did not terminate until the following season of 1892–93, inclusive. Clearly, this decrease must have been due to causes outside of the Gage system of wells. An inspection of the map (p. 116) showing the location of

[a] The rainfall of 1891–92, 14.35 inches, was, however, 1.33 inches lower than the average.

other groups of wells shows near the western border of the Victoria tract two groups of bore holes that might seem to be a contributive cause, viz, the Hunt & Cooley wells, and fourteen or more wells sunk for the domestic water supply of Riverside, between 1888 and the present time. But as a matter of fact the former group had been bored prior to 1889, and the latter, according to the best information obtainable, have not yielded over 250 inches at any time, and have now suffered a diminution to less than one-half their former flow. This depletion of the Victoria wells can not, therefore, reasonably be ascribed to them. Subsequently, between the years 1892 and 1900, a large number of additional wells has been sunk within a short distance (one-half to 1½ miles) from the river, in some cases close to it, so as to make it probable that these wells draw upon the same general store as the bore holes within the Victoria tract. Altogether there were in 1900 over 100 such wells lying along the river's course below the water tract, so that there appears to be sufficient to account for the great reduction in the flows of the original twenty-seven wells, all of which were rather shallow, as are most of the competing bore holes. Later borings were made to greater depths, and have naturally not been so much affected by the multiplication of flows from a higher level. Farther away, along the course of Warm Creek, over forty productive wells are mapped, most of which are tributary to the Riverside water supply. Higher up, toward both sides of the valley, and along the wash of City Creek, there are fifty or more wells, almost all of which originally had an artesian flow, but which now require to be pumped for water. Twenty-two wells on the Raynor tract, on the wash of Lytle Creek just west of the town of San Bernardino, are still flowing; but a number of wells bored only a little higher up on the creek wash now have to be pumped.

It is thus obvious that the indication given by the remarkable fall of the water level on the eastern border (highest point) of the Victoria tract is maintained all around the border of the San Bernardino Valley. The pressure column has fallen materially all over the valley, affecting first, of course, the shallower wells, in the case of which the fall was a large percentage of the entire pressure governing their flow, while the deep wells, of 500 to 700 feet, though showing some diminution, have been much less seriously affected.

DEATH OF VEGETATION.

A noteworthy phenomenon was the dying out of all vegetation, including the largest cottonwood trees, growing on the river bottom lands of the eastern portion of the tract, where formerly the water was within a few feet of the surface. The explanation of this fact is supplied by the highest lying of the wells bored in 1892, near the eastern edge of the Victoria tract, in which the water stood at the surface

at the time, without overflowing. This, the Williams tract well, is 91 feet deep, 1,150 feet above sea level, or about 75 feet higher than well No. 30, which is the highest of the old series of wells. In 1900 the water level in this well was found to have fallen to 26 feet below the surface, leaving it but 49 feet above the surface level of the wells of Group D. It is thus no wonder that the yield of the wells of this group, the most prolific of the original twenty-seven, declined seriously, together with the spring-fed upper reach of the river. The death of the trees was, of course, due to their shallow root system formed above the ground water, which, when the latter declined, could not follow fast enough, so that they were left high and dry.

It is of interest to consider the age of these trees, in view of the fact that a series of drought years—not quite as severe as of late—occurred in the early eighties, as shown in the rainfall table already given. An examination of the growth rings of one of the dead trees, 11 inches in diameter, shows it to have been 18 years old, therefore grown subsequent to the drought years of the early eighties, during which a similar dying out of vegetation might have occurred. There are no records of that time to show whether or not this was the case; nor was the deficiency of rainfall as great as from 1897 to 1900 (11.40 as against 9.12 inches), but none of the older residents remember any such occurrence, which could hardly have failed to attract their notice, the effects of the drought being then the theme of universal comment. Examination shows, moreover, that there are on the same tract of land, near by, several cottonwood trees, 18 to 20 inches in diameter, whose age evidently reaches back into the sixties. It seems probable, therefore, that no fall of the ground-water level such as that which has now taken place has occurred within forty or fifty years at least. Mr. George Cooley, sr., one of the oldest inhabitants of San Bernardino County (since 1857), who dug perhaps the first irrigation ditch on this part of the river, has no recollection of any similar event, although he remembers well the dry years of 1864 and 1865 and the flood seasons of 1861–62 and 1868. He says that he "knows no time in the past when the drought was so great and long continued as during the last four years."

The facts above presented lead to the conclusion that while unquestionably the hitherto unparalleled succession of seasons of scanty rainfall from 1897 to 1900 must be regarded as the chief cause of the depletion of both natural and artificial subterranean outflows, they can not be held accountable for the full amount of decrease observed. Witness especially the unprecedented dying of the old timber on the bottom lands within which formerly the joint waters of the Santa Ana and Mill Creek first reappeared in the river channel, not by direct seepage from the head of the canyons, but by artesian rise from below.

We are led to a similar inference from the decrease of the flow of the original 27 wells of the Victoria tract by nearly one-fourth between 1889 and 1892, a period of high or normal rainfall.

It is true that a certain diminution of the flow of artesian wells is commonly noted as the result of a gradual silting or choking up of the inflow channels or crevices in the bore holes. In extreme cases this obstruction is dealt with, and is relieved, by blasting with dynamite; in ordinary cases, by cleaning out with the sand pump, clearing out the inflow crevices or creating new ones.

But the diminution in the case before us was far more rapid than is observed in the case of such obstructions, and it occurred almost uniformly in numerous wells obviously dependent upon the same source of supply. It can not reasonably be ascribed to anything but a weakening of that source, even within the period of high rainfalls, by the multiplication of flowing wells in the valley.

SOURCE OF THE WATER SUPPLY.

A consideration of the facts given can leave little doubt regarding the derivation of the water supply of both Warm Creek and of the artesian wells of the upper San Bernardino Valley. What we now see happening at and below the mouths of the canyons has happened from the time when the streams first began to pour their floods into the trough of the valley, whose original depths have been filled up to within 20 to 40 feet of the present surface with just such materials as are now brought down in times of flood. This great mass is partially filled with water, annually replenished during the flood season, by the absorption of a portion of the water issuing from the mountains, the rest passing directly to the sea. The Santa Ana River issues from its canyon about 12 miles above the head of the Gage Canal; by barometric measurement it descends about 700 feet in that distance, while Mill Creek issues several hundred feet higher still. The water absorbed by the gravel masses, and afterwards confined between successive clay sheets, might at the head gate of the Gage system, in a well 200 feet deep, possibly be under nearly 1,000 feet of pressure from the head of the valley. No such degree of pressure can, however, manifest itself, if only because of the enormous friction opposed to any movement, and doubtless also because of a steady though slow seepage toward the sea, which relieves it below. It is this steady-moving column that the artesian auger intercepts and taps.

That absorption of surface-flowing water actually does take place in the cobble beds at the canyon outlets is plainly shown in the tunneling operations which have been undertaken in the bed of the Santa Ana River, as well as on Mill Creek. Water was found in these workings at from 20 to 40 feet below the surface. It was dripping in copi-

ous showers from the roof of the tunnel, but the supply was not very large, the leachy floor also causing considerable loss. Yet a portion of the water supply of the town of Mentone was thus obtained from the Mill Creek gravel bed. But as in the case of the tunnel driven into the gravel beds at the mouth of the San Antonio Canyon, already referred to, workings undertaken so high up in a débris cone can rarely attain results commensurate with the heavy cost of excavation work in cobble and gravel beds.

It is quite otherwise in tunneling or boring into the deposits formed at lower levels, where the interstices between the pebbles and cobbles have been more or less filled in with finer materials. This is strikingly illustrated by the "local head" or accumulation of pressure that takes place after an individual well or group of bore holes has been capped. Measured immediately after uncapping, in strong wells that have been closed for some time, the discharge is found to be from 15 to 18 per cent, in very weak wells as much as 36 per cent, greater than that to which the well finally settles down after the lapse of from twenty to thirty hours. This accumulation and slow running down of pressure proves that these vents can not be considered as being connected by a hydrostatic pressure column pure and simple, as is sometimes the case. Manifestly the mass of water is so subdivided by the frequently close-packed materials intervening between the vents made by the auger, and in the interspaces of which the water is stored, that a rapid transmission of pressure is not possible, and the laws of hydraulics and friction so materially modify the hydrostatic effect as to essentially govern the actual discharge of each well. Moreover, the facts observed in 1889 seemed to prove that the water discharged bears but a very small ratio to the total supply that lies behind these artesian fountains.

We evidently have in this great gravel mass, filling the depths of the upper San Bernardino Valley, the same phenomena described above in connection with the débris fan of San Antonio Creek at Pomona. But there is here demonstrated to the eye what near Pomona can only be inferred from the observations made in wells and tunnels, and the very large scale upon which the development has here occurred renders it of much wider importance. From the mouth of Mill Creek Canyon to the cross ridge bordering Lytle Creek on the west the distance is over 15 miles; the average width of the valley within these limits varies, from the Sierra Madre to the foothills on the south, between 9 and 10 miles. The altitude of Mill Creek Canyon mouth above San Bernardino is about 750 feet, and while the earlier wells in Victoria Cienaga, above described, do not reach below 210 feet, other wells have been sunk to the depth of nearly 1,000 feet, near the border of the valley, without striking bed rock; in the axis the depth must be presumed to be considerably greater. The water-bearing gravel mass can not be estimated at less than 15 cubic miles.

FORMER CONDITIONS.

The very large size of the cobbles encountered in the Victoria water tract indicates that the present flood plain here practically coincides with that of ancient times, in which the subterranean stream still moves and toward which, rather than to the sides of the valley, it will always tend. Whether this coincidence of the modern water course with the ancient one is general or only local can not be determined from the facts now known. The general conformation of the country admits of the supposition that the original great stream flowed directly from the head of the valley toward Los Angeles, and that the segregation of the Santa Ana and San Gabriel valleys into separate drainage systems was a comparatively late event. If so, the main subterranean stream may still follow the old channel and could then be tapped by deep borings at points on the line between San Bernardino, Pomona, and Los Angeles. If, on the other hand, there never was a direct flow from San Bernardino peak to Los Angeles, the most productive wells would still have to be sought in or near the present axes of the two valleys.

Considering the conditions set forth above in connection with the large watershed and extensive area, both of absorption and storage, we may reasonably expect that until the ratio of the artificial outflow to the natural supply shall be very materially increased, the boring of additional wells in such favorable localities will continue to yield remunerative returns and to increase very greatly the available water supply of the valley.

While there is reason to expect that the river bottom will furnish the largest outflows, experience has amply shown that bore holes sunk even quite near to the edges of the valley yield good results and may generally be relied upon for a generous domestic supply at least; and in many cases important outflows for irrigation purposes, as well as for the water supply of communities, have been thus obtained. The domestic water supply for the town of Riverside is derived from a group of wells located near the western edge of the Victoria tract; that of the town of San Bernardino from another group of wells located near the wash of Lytle Creek.

THE FUTURE SUPPLY.

The question naturally arises whether in case even of the recurrence of a ten-year period of high rainfall the original masses of water stored in the débris fans of the San Bernardino Valley would be restored, or whether the overdrafts being made will permanently and increasingly diminish that supply, and thus threaten the permanency of the magnificent cultural results now dependent upon regular irrigation.

Upon the points of view formulated above, there are but two methods by which the supply may be made or kept adequate to the cultural demands. The first and easily practicable measure is the reduction of

the waste now incurred; the other is the increased storage of flood waters.

Waste.—As regards waste, it has been thought by some that the copious and continuous flow of the Santa Ana River below Riverside indicates heavy losses from overirrigation above, some having gone so far as to estimate these losses at from 50 to 60 per cent of the water used.

So far as the water rising in the bed of the Santa Ana River is concerned, there is no reason to attribute any large proportion of it, at least, to anything else than the artesian rise, which has always existed, has caused the appropriation, several times over, of "the entire flow of the Santa Ana River" at three or four points, long before irrigation was extensively practiced, and exists equally on Warm Creek and at many points in the upper valley. Mr. William Irving, engineer in charge of the Gage Canal system, assured the writer that for years past the waste from his system from overirrigation and seepage can not have exceeded 10 per cent. It is said, however, that the water table has risen appreciably in some of the lands near the ends of the lower canyon of the Santa Ana, especially at its lower end. If this is true at this time it would certainly argue in favor of the existence of waste from overirrigation above, but the fact must first be fully established.

That some waste did occur in the early nineties from the porous lands lying under the Riverside Ditch, the writer has personally noted. It is not surprising that during the "flush" times of abundant rainfall a lavish use of irrigation water should have become habitual and gradually come to be considered as a necessity, without any better reason than that the results have been satisfactory in most cases. The question whether a less lavish use of water might be made to produce equally satisfactory results has hardly been seriously considered.

In the writer's opinion, based upon numerous cases in which the water used on bearing citrus orchards has been from 30 to 40 per cent less than is usual under the Riverside Ditch, as also upon the experience had at the Southern California Experiment Station near Pomona, it is possible to save a very large percentage of water by simply changing the present method of irrigation in numerous shallow furrows, resulting in the wetting of the entire surface as from a heavy rain, to that of running the water in a few deep furrows, avoiding the wetting of the surface. This will not only do away with the enormous waste from evaporation, but by causing the roots to descend to greater depths will enable them to withstand without injury longer intervals between irrigations, and to draw for their sustenance upon a much larger soil mass than the shallow rooting now induced by overirrigation permits, thus rendering necessary a frequent resort to fertilization that otherwise would have been unnecessary in the exuberantly

VIEW OF SANTA ANA CANYON.

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fertile lands of the region for many years to come. This reform of irrigation practice in the direction of economy, both in the use of water and of fertilizers, is considered as being at present by far the most available means of rendering the diminished water supply adequate to the real needs of the citrus orchards in southern California.

Storage.—An increase in the supply of water in the San Bernardino Valley can be obtained only in one of two ways—the construction of additional artificial reservoirs, like that of the Bear Valley, or the increased absorption of flood waters by the débris fans.

With the possibilities of establishing artificial reservoirs in the mountains, the writer does not pretend to deal. The building of large reservoirs either at the mouth of the Santa Ana Canyon, or elsewhere in the valley at any moderate cost, seems to be precluded by the conformation of the surface. The question arises whether or not it might be possible to increase materially the opportunities for the absorption of flood waters into the cobble and gravel beds near the mouths of the canyons, and thus utilize better than heretofore the storage capacity of the great mass of débris. To this end it would not be necessary to establish costly water-tight basins or dams. Probably important results could be achieved by simply facilitating the spread of the flood water over the gravel surface, and especially by diverting it more than is naturally the case into the short branches or "bayous" which even now are temporarily filled during floods, but are soon emptied, partly by absorption of the water, partly by reflux. The effectiveness of cobble cross ridges in deflecting the flood waters laterally strongly suggests that if nature's work were supplemented by some surface work carefully planned so as to produce the widest spread of the water over the gravel beds, absorption and water storage might be materially increased at comparatively light cost. (Pl. XIV.) The experience had on the San Antonio débris fan, recorded earlier in this bulletin, shows that the overflows may not only be made effective in increasing the flow of artesian wells at a lower level, but that their effect lasts for six months or more, therefore over the irrigation season of the ensuing year.

Of course detailed local surveys can alone determine the feasibility and manner of carrying out such work on the otherwise worthless cobble and gravel areas surrounding the mouths of the canyons. As the effects sought would be beneficial to the entire area of lands drawing upon the subterranean waters of a débris fan, the work would be of a public nature, and the assessment of its cost a matter of considerably greater difficulty and complexity than in the case of water-tight reservoirs and their distributing pipe and ditch systems. But the work could be done gradually, and as its benefits became apparent it would become less difficult to apportion the benefits and cost and to determine its ratio to that of artificial reservoirs and the interest and

sinking-fund charges necessarily connected therewith. It is the writer's impression that the latter would be found materially in excess, even if reasonably good sites for such reservoirs could be found.

It may be thought that if carried out this system of checking flood waters to promote absorption would benefit more largely the deeper wells terminating in coarse cobble beds likely to be directly connected with the central cobble cone at the canyon's mouth than the outflows of Warm Creek and in the Santa Ana River bed. While this is possible, the usual ready response of these flows to the greater or less rainfall suggests that they are likely to respond equally to artificially increased absorption, and that both deep and shallow wells will be benefited.

Very possibly the suggestion here made will be pronounced visionary and impracticable by some who consider themselves eminently practical men. To these the writer has only to say that if they can suggest better means to avert the threatened shortage no one will be better pleased than he.

CHEMICAL COMPOSITION OF THE WATERS.

It is of interest to compare the mineral ingredients of the waters of the San Bernardino Valley among themselves as well as with those of others of similar origin in the State, for it is well known that while some of the artesian waters thus far obtained are very pure others again are so highly charged with mineral matters as to render their use for irrigation impracticable, especially in the presence of "alkali" salts already existing in the soils.

The subjoined analyses of two waters from artesian wells of the Gage system and of the water of Warm Creek, constituting the main bulk of the Riverside Canal, make a very favorable showing for the water supply of the San Bernardino Valley:

Analyses of water from San Bernardino Valley.

[Parts in 10,000.]

Constituents.	Gage system artesian wells.		Warm Creek, at mill.
	Group D, No. 5.	Group A, No. 2.	
Total residue	1.911	2.266	2.604
Soluble part	.418	.488	1.119
Sodium chlorid (common salt)	.063	.091	.257
Sodium sulphate (Glauber's salt)	.193	.313	.582
Sodium carbonate (sal soda)	.102	.021	.200
Potassium sulphate	.060	.063	.080
Insoluble after evaporation	1.493	1.778	1.485
Calcium sulphate		.078	.146
Calcium carbonate	1.017	1.212	.762
Magnesium carbonate	.232	.249	.253
Silica	.244	.239	.324
Summary statement in grains per gallon:			
Total residue	11.16	13.23	15.21
Soluble part	2.44	2.84	6.53
Insoluble after evaporation	8.72	10.38	8.67

FIG. 1.—MACHINE FOR BORING ARTESIAN WELLS.

FIG. 2.—MACHINE FOR BORING ARTESIAN WELLS. WELL JUST COMPLETED.

FIG. 3.—VICTORIA BRIDGE FROM VICTORIA HILLS.

FIG. 4.—TERQUESQUITE ARROYO FROM VICTORIA HILLS.

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Of the solid contents of the waters the portions designated as "insoluble after evaporation" are not only either unobjectionable or useful to vegetation, but are in a short time absorbed and retained in the soil. Their tendency is to render the water "hard" in domestic use, but their quantity in all three waters is very moderate only, considerably less than is found in the waters of the Coast Range generally, where 20 and more grains per gallon, of which two-thirds is of the insoluble character, is of common occurrence.

Most important to the irrigator, however, are the soluble or saline ingredients, which, when in large amounts, represent so much alkali added to a soil perhaps already alkaline. It will be seen that these ingredients are in the well waters represented by the very small amount of about 2⅗ grains (taking the average), being only a little more than is found in the water of Kern River, and about one-third of the corresponding contents of the Los Angeles River, the latter having 17½ grains of total mineral contents.

It will be noted that the water of Warm Creek, while having no more of the insoluble or earthy ingredients than the wells, carries more than twice as much of the soluble or saline compounds; whether orginally or from outside accessions, is not clearly apparent from the nature of the salts. The quantity of these salts is not yet large, and is, moreover, of little consequence in the porous and well-drained soils of Riverside.

There is, however, one point that must not be passed over in the valuation of these waters for irrigation purposes. It is the unusually large proportion of potash salts obtained in them which, at the rate at which water is commonly used in that region, say 1 inch to 5 acres, will suffice to provide all that most crops require of that important fertilizer. For with the full use of one-fifth inch through each year (corresponding to a rainfall of nearly 35 inches) each acre would currently receive no less than 47 pounds of potash sulphate, worth over $1.65 at wholesale, from the well water, and about 63 pounds of the same from the creek water. Considering the quality of the soil, this means that the purchase of potash fertilizers need not soon trouble the irrigators of Riverside. Considering the nature of the rocks prevailing in the Sierra Madre, viz, granite containing a very large proportion of potash feldspar, this fact is not unexpected and may be presumed to hold true of the waters of the valley of southern California generally.

THE TEMESCAL CREEK DRAINAGE SYSTEM.

Temescal Creek is the only considerable tributary flowing into the Santa Ana River from the south. At the present time its length is inconsiderable (22 miles), and in ordinary summers its bed is dry for about 5 miles above its mouth; not so much because of total lack of

water as because, like so many other streams of middle and southern California, it loses itself in the porous deposits of gravel and sand that have been formed in the valley where it opens into the plain of the Santa Ana. The flow of Temescal Creek at the present time is almost wholly derived from the drainage of the northern and eastern slopes of the Santa Ana Mountains, which divide the San Bernardino Valley from the coast plain of Orange County. Through the western spur of this mountain chain the river has carved a narrow gorge, close to the northern end of which Temescal Creek joins the river. From the northern slope of the Santa Ana Mountains, adjacent to the lands of the Corona town site, only small streams descend, requiring storage reservoirs for their utilization. Such are Hagador and Lords canyons, and farther up, on the eastern slope, Mannings, Damrons, Whites, and Andersons cienagas. The cause of the relatively small flow from these gorges is manifestly the nature of the geological formation of the foothills, which near their base is partly a structureless red loam, corresponding to that seen at the base of the Sierra Madre opposite, which has materially contributed to the formation of the soils below; while farther back lie the whitish, sandy clays of the Tertiary, in which likewise water-shedding strata are rare, and springs therefore quite scarce and scanty in flow. None of these gorges reach far enough back into the rocky central mass that occupies the higher portion of the range, with its relatively abundant rainfall, to receive any of its drainage.

Ascending the Temescal Valley, Coldwater Canyon is the first that yields a permanent flow of any importance; and still above, Mayhew, Peter Wall, and Horsethief canyons carry from the higher crests streams that flow throughout the year as far as their rocky beds reach. The width of the Temescal Valley in this upper portion is from 1 to 1½ miles between the opposite slopes; but within lie narrow bodies of low hill or mesa land, more or less connected into a continuous ridge running lengthwise of the valley, and dividing it into two unequal portions. Through the narrow one, mostly hugging the foot of the eastern or Temescal Range, flows the main creek; while more or less definite washes, crossing the central ridge at several points, mark the places where in times of flood the waters of the several canyons find their way from the Santa Ana Mountains to the main channel. These washes are formed of great masses of débris, the material of which is mostly granitic sand and gravel, and often huge bowlders of the same rock, and of silicious schist banded black and white, indicating both their origin in the high range and the copious rainfall prevailing there. Continuous flows are rarely seen in these washes, and then only for short times. The porous nature of the materials explains sufficiently the disappearance of the water. Only insignificant rills come down from the steep slopes of the Temescal Range on the east, and

even Sheep Creek, with its considerable watershed to eastward of the upper course of Temescal Creek, ordinarily yields but a very scanty flow to the latter.

About 11 miles above the Corona town site there is a long, shallow lake basin, about 80 acres in extent, called, from the first settler in the neighborhood, Lees Lake. From the lower end of this largely tule-covered basin issues the ordinary flow of Temescal Creek; while ordinarily little or no flow enters at the upper end. Examination of the western margin of Lees Lake shows that it is fed by numerous springs, amounting in many places to continuous copious oozes for many yards, coming from the Santa Ana side of the valley, and most abundant directly in front of Horsethief and Peter Walls canyons. It is obviously the flow of these gorges, absorbed within the great masses of débris they have deposited between their exits from the Santa Ana Range and the course of the main creek at the foot of the opposite slope, that with slow movement feeds the lake and the flow of the creek at its outlet, amounting in the dry season to about 400 miner's inches. We evidently have here on a small scale the same conditions which give rise to Warm Creek in the main valley, the great masses of débris serving as natural storage reservoirs conserving and equalizing the water supply through the season, instead of permitting it to rush ruthlessly to the sea at flood time.

While in the case of these two canyons we have a slow continuous seepage toward the drainage channel, a different state of things is seen at the mouths of Mayhew and Coldwater canyons. Here also large masses of débris have been accumulated by the mountain torrents, but owing to the intervention of the longitudinal ridge dividing the valley, already referred to, the bowlders, gravel, and sand have been banked up against the practically impervious dam of clayey strata. In front of Mayhew Canyon there is a narrow pass through which in times of high water there is a more or less considerable flow; but wells sunk near by prove that the gravel wash is only superficial, so that no considerable underflow can pass from the canyon to the creek. Substantially the same conditions exist at the mouth of Coldwater Canyon, where also occasionally flood waters are poured directly into Temescal Creek.

The natural result is that these gravel masses, absorbing and storing the mountain waters, have formed an extensive tract of moist cienaga land, from which water bursts forth at numerous points in the form of springs, and from which a further supply can be drawn by means of artesian borings, or, as has actually been done, by tunneling from a lower level. In an experimental tunnel so driven at Rileys Cienaga, a flow of 25 to 30 inches rushed forth through a small hole, as soon as the last of the clay wall was broken through, 40 feet below the surface. As these cienagas illustrate very well their various phases of

development, it is desirable to discuss them somewhat in detail. The areas which may be properly designated as cienaga land, characterized by the peculiar black soil of such localities, may be enumerated as follows, proceeding downstream:

THE COMPTON CIENAGA.

The Compton Cienaga embraces about 20 acres of absolutely wet or tule land, overgrown with the round rush (*Scirpus lacustris*) and 140 acres of merely moist or subirrigated land. It lies about midway between the mouths of Mayhew and Coldwater canyons, and but a short distance from the foot of the longitudinal clay ridges of the valley. From the wet portions of this tract there has always been a steady surface flow of from 50 to 60 inches of water. Three artesian wells have been bored within the tract, one to the depth of 300 feet and the others to about 100 feet, all in granite gravel. There appeared to be no material increase of flow with greater depth, the wells yielding each from 20 to 25 inches of water. In a pipe laid to supply a schoolhouse near by the water of well No. 3 rose to 25 feet above its mouth.

THE ROLFE CIENAGA.

The Rolfe Cienaga, distant from the preceding one about one-fourth mile southeastward, just below the wash of Coldwater Canyon, contains 314 acres of wet land, which is so full of springs and, in consequence of the luxuriant vegetation, so dangerous for roaming cattle, that it has been fenced for safety. Four 10-inch wells have been sunk here to depths ranging from 125 to 145 feet, all in granitic gravel. The flow from these borings is much more abundant than from the Compton Cienaga. Before the borings were made the surface flow was about 300 inches, and it is stated that it has not been sensibly diminished since the wells began to flow, discharging an average of about 228 inches. Thus the total flow from the two cienagas amounts to about 600 inches, exceeding considerably the flow of Temescal Creek at the foot of Lees Lake.

THE RILEY CIENAGA.

The Riley Cienaga lies about three-fourths of a mile due north from the wells of the Rolfe Cienaga; its area is only 7 acres. Like the Rolfe Cienaga, it lies on the course of the Coldwater Wash, which here passed right at the base of the clay ridge that skirts it on the east, while a clay ridge closes in within a few hundred yards on the west side also. It was here that, as mentioned above, a tunnel was driven at a lower level and received a 25-inch stream when the clay wall was broken through into the cienaga gravel mass. No borings had at that time been made in this cienaga.

THE HARRINGTON CIENAGA.

The Harrington Cienaga lies 2¼ miles below, on the course of the main creek, here traversed by granite ledges which, by checking the current, have caused a heavy deposit of bowlders, gravel, and sand on an oval area of about 7 acres. The water is almost fully absorbed at the upper end of the tract, but its full flow is forced to the surface by the bed rock below and passes over it as a waterfall. The moist land above is largely overgrown with willows and cottonwoods. No wells have been bored here, since evidently all the water can be made available at the falls, the altitude of which is 842 feet above tidewater.

Below the Harrington Gorge, Temescal Creek gradually decreases in volume as its waters sink into the gravel beds, and in seasons of ordinary rainfall it does not carry any visible flow beyond the bridge on the Riverside road (Magnolia avenue) which forms a straight line from that city to the Corona town site. In June, 1890, however, it not only flowed past the town site itself but reached the Santa Ana as a definite stream, flowing mostly along the southern foot of the Auburndale Hills which lie between it and the main valley.

COMPOSITION OF THESE WATERS.

The table below shows the composition of the water of the artesian wells of the Rolfe Cienaga on the one hand and of Lees Lake water on the other, as found in the summer of 1890, and also the water of Lees Lake as found in the summer of 1901, after three years of unusually light rainfall.

Analyses of water from the Rolfe Cienaga and from Lees Lake.

Constituents.	Artesian well.		Lees Lake.			
	June 24, 1890.		August 31, 1890.		1901.	
	Grains per gallon.	Parts per 10,000.	Grains per gallon.	Parts per 10,000.	Grains per gallon.	Parts per 10,000.
Total solid contents	13.20	2.260	14.14	2.425	36.15	6.20
Strictly mineral matter	12.00	2.054	12.25	2.147	31.49	5.40
Soluble after evaporation	3.96	.679	2.77	.475	20.41	3.50
Sodium chlorid (common salt)	.55	.094	1.00	.170	10.86	1.85
Sodium sulphate (Glauber's salt)	2.11	.361	.71	.123	8.81	1.52
Sodium carbonate	.55	.093	.50	.085	.74	.13
Potassium sulphate	.75	.131	.56	.096	Small.	Small.
Insoluble after evaporation	8.03	1.375	9.68	1.672	11.08	1.90
Calcium sulphate (gypsum)	.88	.151	.13	.022	....	....
Calcium carbonate	4.49	.770	5.76	1.000	....	....
Magnesium carbonate	.80	.137	.82	.141	11.08	1.90
Peroxid of iron	.06	.012	.11	.020	....	....
Silica	1.80	.305	2.86	.490	....	....
Organic matter (small) and water	1.20	.205	1.68	.280	4.66	.80

It will be noted that there was on the whole very little difference between the water of the artesian well and that of Lees Lake in 1890. The lake water contains a larger percentage of earthy as well as of

organic matter, the natural result of the retention of the water in a basin full of aquatic vegetation. Yet this sample, taken on the bank of the lake near to the springs or oozes referred to as coming from the débris beds, hardly represents fully the condition of the water in the main body of the lake basin, which doubtless would have shown more of both ingredients. The sample of 1901, on the contrary, was taken at the outflow of the lake, and shows the effects on the quantity of the mineral elements of the water produced by three seasons of exceptionally short rainfall. We see here that the content of soluble salts has been increased over seven times, that of common salt nearly eleven times; while the earthy portion is not greatly in excess of the former figure, although the organic matter is fully doubled. It is not altogether easy to understand the cause of this marked increase in common salt, the most objectionable ingredient for irrigation purposes, although not yet in such excess as to form a serious objection to the use of the water. The marked change in the proportion between the sulphate and chlorid of sodium, approaching that existing in Elsinore Lake (see below), would seem to argue that some contamination of Lees Lake from that source has occurred.

CONNECTION WITH THE SAN JACINTO DRAINAGE BASIN.

As we ascend the Temescal Valley above Lees Lake we find, aside from Sheep Creek, but a few insignificant rills tributary to the main stream. But the channel of the latter continues onward to the southeast very plainly marked, sometimes assuming the character of a rocky canyon, and finally opens out upon the alluvial plain surrounding the Elsinore Lake basin, which is the final recipient of the flow of the San Jacinto River heading 52 miles away in the San Jacinto Range, on the border of the Colorado Desert. In other words, Temescal Creek is the natural outlet of Elsinore Lake, but actual flow occurs at long intervals only. In 1890, an unusually rainy season, it flowed for four months, finally ceasing on July 25. Quite a lively stream flowed in the connecting channel at the time of the writer's visit, and while this flow lasted the water of Lees Lake appeared frothy, and at the riffles in the creek below the water seemed as though charged with soapsuds. The last previous occurrence of a flow from Elsinore Lake was in 1884; the last previous to that in 1864. Nor is there any underground connection between Elsinore Lake and Temescal Creek, as might be conjectured; the sinking of wells and mining for lignite have shown that solid clay beds intervene, over the surface of which any connecting flow must occur. That such is the case is also proved by the character of the lake's water which is quite brackish, to a degree varying according to the rainfall in the San Jacinto Mountains. This variation is well shown in the subjoined analyses, showing the composition of samples taken in four different years. Possibly, however, these samples were not all taken from the same point in the lake:

Composition of the water of Elsinore Lake.

Constituents.	A.		B.		C.		D.	
	Grains per gallon.	Parts in 10,000.	Grains per gallon.	Parts in 10,000.	Grains per gallon.	Parts in 10,000.	Grains per gallon.	Parts in 10,000.
Total residue by evaporation	108.21	17.67	84.34	14.44	98.42	16.85	116.18	19.89
Soluble in water after evaporation	95.21	16.30	71.84	12.30	88.20	15.10	98.54	16.87
Insoluble in water after evaporation	2.75	.47	5.96	1.02	5.84	.10	9.46	16.20
Organic matter and chemically combined water	5.25	.90	6.54	1.12	4.38	.75	8.18	1.40
The soluble part consists of—								
Sodium and potassium sulphates (Glauber's salt, etc.)	76.00	13.00	14.85	2.55	20.11	3.44	22.03	3.77
Sodium chlorid (common salt)			43.37	7.42	47.05	8.05	53.62	9.18
Sodium carbonate (sal soda)	19.21	3.30	13.62	2.33	21.04	3.60	22.89	3.92
The insoluble part consists of—								
Calcium and magnesium carbonates	2.75	.47	5.49	.08	4.96	.85	7.01	1.20
Calcium sulphate (gypsum)	....	....	....	....	....	....	....	....
Silica	Trace.	....	.47	.94	.88	.15	2.45	.42

While it is of course not certain that the samples analyzed represented the true average composition of the lake water at the several dates, having been taken by residents without special instructions, the fact that these residents were directly interested in the question of the fitness of this water for irrigation renders it probable that common sense procedures were employed in the taking of the samples, and that the differences are merely due to the variations that unavoidably occur in shallow lake basins subject to evaporation. In 1890 there was a question regarding the use of the water for irrigation of the lands around the town of Elsinore, and as the conclusion from analyses, the writer strongly advised that no such attempt should be made, as it would surely result in the excessive impregnation of the lands irrigated with alkali salts. Recourse was then had to artesian borings, which resulted quite favorably, as is illustrated in the two analyses below:

Analyses of water from artesian wells near Elsinore.

E. Z. BUNDY.

Constituents.	1890.		1898.	
	Grains per gallon.	Parts in 10,000.	Grains per gallon.	Parts in 10,000.
Total residue by evaporation	19.28	3.30	16.23	2.78
Soluble in water after evaporation	12.85	2.20	9.46	1.62
Insoluble in water after evaporation	5.55	.95	4.32	.74
Organic matter and chemically combined water	.88	.15	2.45	.42
The soluble part consists of—				
Sodium and potassium sulphates (Glauber's salt, etc.)	5.02	.86	6.97	1.19
Sodium chlorid (common salt)	1.64	.28	.64	.11
Sodium carbonate (sal soda)	6.19	1.06	1.85	.32
The insoluble part consists of—				
Calcium and magnesium carbonates	2.04	35	....	....
Calcium sulphate (gypsum)	....	....	3.80	.65
Silica	3.51	.60	.52	.89

Aside from the very moderate saline content of these waters, which leaves them suitable for all ordinary purposes, it is interesting to note the great difference in the proportion of the two chief salts, common and Glauber's, when compared with the lake water. In the latter the common salt exceeds the Glauber's salt in the ratio of three to one, and practically the same ratio is maintained in the water of Bundy's well analyzed in 1890, while in that analyzed in 1898 the common salt is only one-tenth as much as the (for irrigation purposes) relatively innocuous sulphate. In this respect these waters are quite similar to those of the cienaga waters in the Temescal Valley.

It is also of interest to consider the nature of the water of San Jacinto River, whose inflow maintains the water supply of Elsinore Lake. This stream, though of considerable length from its head in the San Jacinto Range, does not carry its water visibly into the lake every year, although some underflow is probably annually supplied from the gravel beds at its mouth. At the time the sample analyzed was taken, in the summer of 1900, there was no flow, and there had been none for at least twelve months, but the water sampled stood in the bed of the stream apparently connected with underground seepage toward the lake, since it had not the aspect of being stagnant.

Analysis of the water of the San Jacinto River.

Constituents.	1901.	
	Grains per gallon.	Parts in 10,000.
Total residue by evaporation	31.76	5.45
Soluble in water after evaporation	19.82	3.40
Insoluble in water after evaporation	7.57	1.30
Organic matter and chemically combined water	4.37	.75
The soluble part consists of—		
Sodium and potassium sulphates (Glauber's salt, etc.)	9.09	1.56
Sodium chlorid (common salt)	9.50	1.62
Sodium carbonate (sal soda)	1.23	.22
The insoluble part consists of—		
Calcium and magnesium carbonates; Calcium sulphate (gypsum), large	5.24	.90
Silica	2.33	.40

While the saline content of this water is somewhat high, it would usually be used unhesitatingly for all ordinary purposes, although doubtless of slightly laxative effect upon some persons. That it is not much more highly charged with salts is, at first sight, somewhat surprising considering the large area of alkali, or rather saline, lands traversed by it. As high up in its course as the town of San Jacinto, but a few miles away from the foot of the range of that name, its bottom lands are more or less alkaline, sometimes highly so, and the same state of things is observed almost throughout its course to a greater or less extent. In the Perris Valley this is the case, so that in digging wells near the central line of that valley saline layers are

found to exist bodily at the depth of 10 to 15 feet, and at some points strongly saline water wholly unfit for any ordinary use is found.

The explanation of the relatively low content of salts in the river water is simple enough. It is very pure as it comes from the high mountains, but increases its saline content gradually from the flows entering it from lower levels. But as it reaches the valley, with its hot, dry air and powdery soils, the lateral absorption is considerable, and rapid evaporation from the moistened banks takes place. The seepage is thus always outward from the stream, and a relatively pure water flows between banks upon which copious efflorescences of salts are seen during most of the year. This is also strikingly seen in ditches fed by Kern River, which some distance south of Bakersfield pass through strongly alkaline lands. Here, as observed by the writer in 1880, the earth thrown up from the ditches was in the dry season so thickly covered with saline matter that it could be scooped up by the handful; yet the comparative analyses of the river water at the mouth of the canyon and the ditch water 10 miles below showed practically no difference in the saline contents of the two samples.[a]

When we compare the saline ingredients of the San Jacinto River water with those of the Lake Elsinore water, we note that the difference is not only quantitative but qualitative also. In the lake water nearly half of the saline content is common salt and less than one-fourth is sulphate, while in the river water the sulphate is nearly equal in amount, and it and the carbonate of sodium taken together somewhat exceed the chlorid.

This change is doubtless due to the effect of the vegetation in the lake, which by the evolution of carbonic acid causes the lime carbonate present to react with the sodium sulphate so as to form sodium carbonate and gypsum.[b]

EFFECTS OF THE DRY SEASON 1898–1901.

At the time of the examination of the Temescal water supply by the writer, in 1889, a season of copious rainfall had, as stated above, caused Elsinore Lake to overflow into Temescal Creek through the existing channel. The water-measurements made during this and previous seasons had given the available water supply from the creek and cienagas at from 1,000 to 1,100 inches, which at the duty of water adopted at Riverside, 1 inch to 7 acres, would, with reasonable care in the mode of application of the water, have irrigated effectively 7,000 acres of land. The water company, however, was anxious to develop more, in view of future expansion, and contemplated the establishment of reservoirs for the storing of flood waters. Financial means for

[a] California Sta. Rpts. 1886, Appendix 7, p. 28; 1890, p. 52; 1897–98, p. 113.
[b] California Sta. Rpts. 1888–89, Advance sheets, p. 51; 1890, p. 100.

this purpose, however, could not be provided, and thus the extraordinary succession of three dry years from 1898 to 1901, by gradually diminishing the estimated water supply, caused the company to resort to Elsinore Lake as a source of increase, available especially for the lower levels of the Corona settlement. The evil results of this use soon became apparent, as had been predicted by the writer in 1890. The orchards wholly or partially irrigated with the lake water began to show serious signs of distress in 1898, and still more in the following year; so that at the request of the orchardists of the Corona neighborhood an elaborate examination of the soil conditions of the suffering orchards was undertaken by the California station. The examinations made by Dr. R. H. Loughridge of both the soils and the waters are reported and discussed in detail in the station report for 1897–98, pp. 99–113. It was shown that during the four years since the use of the Lake Elsinore water was begun the saline contents of the lands so irrigated had, according to the amounts used, increased from about 1,300 pounds per acre to as much as 16,000 pounds—near the irrigation ditches, 19,000 pounds—while the largest amount found in land irrigated with the cienaga (artesian) water was 3,240 pounds. Even this latter increase would doubtless have been much less but for the necessity of using the water very sparingly, so that all the salts accumulated in the land. This evil was aggravated by the previous existence or formation of a hardpan at a depth of 1½ or 2 feet, which prevented the penetration of the water to the proper depth and left the lower roots of the trees dry.

The irrigators of southern California have often questioned the wisdom of the writer's injunction that when saline water must be used in order to save the life of an orchard it should be used only in deep furrows and also quite abundantly. The former prescription implies that the more surface evaporation is prevented the less the saline water is concentrated, and the more water is used the more surely any accumulation of salts in the soil from the inevitable evaporation is prevented. It is indeed quite rarely that natural waters away from the sea or landlocked lakes are sufficiently strong in saline contents to effect directly the roots of any but young plants, which are much more sensitive to the injurious effects of alkali salts of all kinds than the thicker and harder roots of other plants.

As a result of the investigations of the California station the use of the Lake Elsinore water was abandoned, but as the drought lasting from 1898 to 1901 had so far reduced the supply derivable from the cienagas and from Temescal Creek that it was insufficient to more than keep alive the numerous orchards dependent upon it, the water company sought for other sources of supply and obtained a material addition from wells bored on the eastern slope of the Perris Valley, 30 miles away.

Definite figures in regard to this addition have not been obtainable, but the analyses of the water piped from the wells in question gave the following result:

Analyses of water carried in the pipes of the water company at Corona, Cal.

Constituents.	Grains per gallon.	Parts in 10,000.
Total residue of evaporation	18.66	3.20
Soluble in water after evaporation	6.41	1.10
Insoluble in water after evaporation	9.33	1.60
Organic matter and chemically combined water	2.92	.50
The soluble part consists of—		
Sodium and potassium sulphates (Glauber's salt, etc.)	2.46	.43
Sodium chlorid (common salt)	2.70	.46
Sodium carbonate (sal soda)	1.25	.21
The insoluble part consists of—		
Calcium and magnesium carbonates		
Calcium sulphate (gypsum)	9.33	1.60
Silica		

It will be seen that although somewhat higher in saline content than the waters of the main San Bernardino Valley, and also above that of the waters of the cienagas and of Lees Lake as ascertained in 1890, the saline content is by no means so great as to interfere with the use of the water for irrigation and domestic purposes; and it is to be hoped that the quantity supplied by the costly pipe line of the water company will be found sufficient for the needs of the Corona colony until an increased rainfall shall reestablish normal conditions in the home supply.

THE SAN GABRIEL RIVER DRAINAGE SYSTEM.

While the San Gabriel Valley does not properly fall within the limits designed for this paper, some general remarks on its character as compared with the Santa Ana Valley seem appropriate. The San Gabriel River, from its proximity to Los Angeles and San Gabriel Mission, was probably, with the Los Angeles River, the first of the larger streams of the State utilized for irrigation. It was here that an organized system of irrigation was developed, and the "zanjero" early regulated the times and amounts of water due to each irrigator, with an authority not easily called in question, for with a relatively dense population such regulations were clearly seen to be essential to the public welfare, the visible water supply being quickly applied to actual use. When the visible supply began to prove inadequate to the demand, the subterranean sources began to be explored; and it was soon seen that a material addition to the total supply could be secured by means of simple drainage ditches, cut into the level alluvial lands of the wide plain open toward the sea, which forms the lower valley of

both rivers. In this respect this valley is quite unlike that of the Santa Ana River, described above. The mountains in which the San Gabriel heads, being of less height than those whose melting snows often supply the flow of the Santa Ana River until late in the season, it does not bear so strikingly the character of the mountain torrent, albeit during and after heavy rains it also carries heavy bowlders to the canyon mouth. But its débris fan is much less pronounced in character than that of the Santa Ana, its slope very much less, and the materials generally of a finer grade. From San Jose Creek, near the western spur of the Puente Hills, to the mouth of the San Gabriel Canyon, there is an ascent of only 500 feet in 9 miles; while from the same stream near Pomona to the mouth of the San Antonio Canyon the ascent is 1,250 feet in nearly the same distance. That correspondingly steep slopes prevail in the upper San Bernardino Valley has already been shown. To the eye the San Gabriel Valley appears as a level plain until the foot of the Sierra Madre is approached; and when water appears in the much-branched washes of the river, its flow is much more sluggish than that of the Santa Ana.

Correspondingly, wells bored in this valley rarely have as large flows as are common in the San Bernardino Valley, and frequently yield water only by pumping. Lower down good outflows are obtained in deep borings, both in the San Gabriel and Los Angeles valleys; but the quality of these waters is not as uniform as on the Santa Ana, and not uncommonly they are rather strongly mineral. On the other hand, there is in the San Gabriel and Los Angeles River valleys a good deal of subirrigated land, the lowering of whose water table by ditches for water development has at times given rise to much complaint and contention. It will thus be seen that the conditions of subterranean water supply in the two subdivisions of the valley of southern California differ quite materially.

DUTY OF WATER UNDER GAGE CANAL, RIVERSIDE, CAL., 1901.[a]

By W. Irving, C. E.

During the past year the weather conditions have been less favorable for the development and growth of citrus fruits than during the year previous, and as a consequence the crop will fall short of the estimate made in the early part of the season. This shortage is largely due to the reduced average size of the fruit, requiring a greater number of specimens to each box. In addition to this cause the whole of southern California was subject to a very low dip in temperature during the

[a] For description of canal system and land irrigated see U. S. Dept. Agr., Office of Experiment Stations Buls. 86 and 104.

nights of December 13 and 14, resulting in more or less damage to the fruit, and causing a further reduction in the total volume. This total reduction has been variously estimated at from 25 to 35 per cent from the crop of 1900; but the actual result can not be definitely determined until the end of the shipping season, the shipping season as determined by the Southern California Fruit Exchange being from September 30 to September 30 each year. The crop of last season, however, was abnormally large, reaching a total for southern California of over 25,000 carloads, or 9,050,000 boxes, there being on the average about 362 boxes to each car. The percentage of decrease above referred to may be considered general for all localities in the southern parts of the State where citrus fruits are grown.

The total shipments from Riverside Station, as shown by the official returns from railroad companies, was 5,643 cars, including lemons and grape fruit, making in all 2,042,766 boxes, on the same computation of boxes per car as used above.

The particular local territories from which this product was taken and shipped from Riverside Station are the following:

Riverside (old settlement), under Riverside canals.

East Riverside, under Gage Canal system.

Arlington Heights, under Gage Canal system.

San Jacinto Land Company, under Gage Canal system.

West Riverside, under the Jurupa Canal.

Riverside Highlands Company, under "Vivienda" pipe line.

The water supply, acreage, and products of each of these subdivisions will form part of the work of investigation for the coming year, and will be fully reported on at the end of the season.

TEMPERATURE AND RAINFALL.

The following tables give the details regarding weather conditions for the season of 1900–1901 in the vicinity of Riverside:

Temperature at Raeburn, Arlington Heights, Cal.

Month.	Mean maximum.	Mean minimum.	Maximum.	Minimum.
	°F.	°F.	°F.	°F.
November, 1900	77.58	50.95	92.00	44.00
December, 1900	72.29	46.27	83.00	34.75
January, 1901	63.44	42.87	76.25	33.00
February, 1901	66.00	45.44	88.00	30.00
March, 1901	74.15	45.40	90.00	34.50
April, 1901	73.12	43.88	83.00	36.00
May, 1901	73.47	51.08	83.50	44.00
June, 1901	83.75	53.99	107.00	49.50
July, 1901	92.88	58.45	99.00	52.00
August, 1901	91.28	59.80	104.00	52.00
September, 1901	81.60	51.00	90.00	45.00
October, 1901	79.00	51.40	94.00	43.00

Rainfall at Arlington Heights, November, 1900, to October, 1901.

Date.	Rainfall.	Date.	Rainfall.
1900.	*Inches.*	1901—Continued.	*Inches.*
November 16	0.08	January 31	0.30
November 17	1.05		2.68
November 18	.06	February 1	.12
November 19	.24	February 2	.18
November 20	.24	February 3	.22
November 21	.27	February 4	.14
November 22	.57	February 5	.92
	2.51	February 6	.28
1901.		February 7	.08
January 5	.13	February 8	.51
January 6	.57	February 9	.44
January 7	.60		2.74
January 8	.02	March 11	.12
January 20	.01	Total rainfall	8.04
January 21	.23		
January 25	.10		
January 27	.68		
January 28	.04		

DISTRICT NO. 1.

The tables which follow give the average flow of water delivered to the lands in district No. 1 from November 1, 1900, to October 31, 1901. No water is delivered from the canal when a sufficient quantity is furnished by rainfall. On this account the canal was shut down one day in November, 1900, five days in January, 1901, and six days in February, 1901. The average flows given in the table are obtained by dividing the total flow for each month by the number of days in the month rather than by the number of days when water was used.

Water used in district No. 1, under Gage Canal, November 1, 1900, to October 31, 1901.

Month.	Miner's inches.	Acre-feet.	Month.	Miner's inches.	Acre-feet.
November	445	529.59	June	654	778.33
December	202	248.41	July	673	827.64
January	249	306.21	August	688	846.08
February	159	176.68	September	675	803.32
March	571	702.20	October	601	739.09
April	651	774.76			
May	607	746.47	Year	516	7,478.78

Duty of water, district No. 1.

Area irrigated	acres..	3,614.00
Water used	acre-feet..	7,478.78
Depth of water used in irrigation	feet..	2.07
Depth of rainfall	foot..	.67
Total depth of water received by land	feet..	2.74

CROP RETURNS.

It is almost impossible to get absolutely correct returns of products from private parties, especially when a large number of them hesitate

to make public their private affairs. The returns given in the following table are actual returns from particular tracts, furnished by packers, although the names of the owners of the tracts are unknown to the writer. The ages of particular tracts are not given, but all the trees were planted before the year 1892. The product is principally navel oranges.

Crop returns from nine orchards in district No. 1, under Gage Canal, California, 1900.

Number of orchard.	Area.	Product.		
		Total.		Per acre.
	Acres.	*Pounds.*	*Boxes.*	*Boxes.*
1	10	241,196	3,547	354.7
2	10	144,187	2,120	212
3	10	221,842	3,262	326.2
4	10	273,236	4,018	401.8
5	10	152,037	2,235	223.5
6	10	228,600	3,362	336.2
7	5	72,530	1,066	213.2
8	10	203,760	3,000	300
9	10	182,025	2,677	267.7
Total	85	1,719,413	25,287	297

These samples represent fairly enough the normal product of trees at the ages given and subject to average good care. Many cases could be given of greater, but abnormal, productiveness, the result of excessive stimulation, but this would not be representative of the best treatment or of a common practice in this locality.

The navel variety of orange tree, other conditions remaining equally favorable, will continue to increase in productiveness until it reaches as great as 600 boxes per acre—say at the age of 16 years. This, of course, varying with the seasons and other conditions.

DISTRICT NO. 2.

In district No. 2 no water was delivered during eight days in November, 1900; three days in December, 1900; three days in January, 1901; six days in February, 1901, and seven days in March, 1901. The averages are made up for the whole number of days in each month, as explained in the report of district No. 1. The following table gives the average volume of water delivered to district No. 2:

Water used in district No. 2, under Gage Canal, November 1, 1900, to October 31, 1901.

Month.	Miner's inches.	Acre-feet.	Month.	Miner's inches.	Acre-feet.
November	342	407.01	June	631	750.95
December	155	190.61	July	558	686.21
January	152	186.93	August	656	806.73
February	71	78.96	September	642	754.04
March	269	330.78	October	610	750.16
April	643	765.23			
May	713	876.83	Year	454	6,584.44

Duty of water, district No. 2.

Area irrigated	acres..	3,237.84
Water used	acre-feet..	6,584.44
Depth of water used in irrigation	feet..	2.03
Depth of rainfall	foot..	.67
Total depth of water received by land	feet..	2.70

CROP RETURNS.

The crop returns given below are from tracts in district No. 2, the owners of which are well known to the writer, but whose names are withheld. The areas given exclude small fractions. Generally the acreage is a fraction less than that given.

Crop returns from ten orchards in district No. 2, under Gage Canal, California, 1900.

Number of orchard.	Area.	Product.			Age of trees.
		Total.		Per acre.	
	Acres.	*Pounds.*	*Boxes.*	*Boxes.*	*Years.*
1	5	139,400	2,050	410	9
2	10	156,536	2,302	230.2	7
3	10	274,720	4,040	404	8
4	10	231,200	3,400	340	9
5	17	524,066	7,707	453	9
6	10	273,207	4,017	401.7	9
7	10	166,600	2,450	245	9
8	20	356,320	5,240	262	8
9	10	244,800	3,600	360	9
10	20	484,500	7,125	356.2	9
Total	122	2,851,349	41,931	343.7	....

The above tracts are the total holdings of the several owners, but of course form only a small part of the whole area of the district. In all the cases above referred to the whole product consists of oranges of the "navel" variety, and planted between the years 1891 and 1893, and while receiving no more than the regular allowance of water, the amount of fertilization would be in excess of the average applied to the lands of this section.

The remaining lands in district No. 2 in the hands of private owners and planted previous to the year 1894 consist of 751 acres. Estimated on the foregoing actual returns, but making a reasonable reduction for any difference of treatment in the cultivation and fertilization of the lands, say from an average of 343.7 boxes to 275 boxes per acre, a general average for all lands in the district planted prior to 1894 owned by said parties would be 285 boxes per acre.

DISTRICT NO. 3.

The following table gives the monthly average volumes of water delivered to district No. 3. As will be seen by referring to the table, no water was used during February, 1901:

Water used in district No. 3, under Gage Canal, November 1, 1900, to October 31, 1901.

Month.	Miner's inches.	Acre-feet.	Month.	Miner's inches.	Acre-feet.
November	43	51.17	June	104	123.77
December	3	3.69	July	78	95.92
January	4	4.92	August	108	132.82
February	0	.00	September	107	127.34
March	36	44.27	October	72	88.54
April	91	108.30			
May	100	123.57	Year	62	904.31

Duty of water, district No. 3.

Area irrigated	acres..	650.00
Water used	acre-feet..	904.31
Depth of water used in irrigation	feet..	1.39
Depth of rainfall	foot..	.67
Total depth of water received by land	feet..	2.06

No crop returns were collected in district No. 3. It should be particularly noted that the returns given for districts Nos. 1 and 2 refer to the year ended September 30, 1901, and therefore should form a part of the report made last year. Owing to the length of time before the marketing of the citrus crop it is not possible to give the quantities of water used and the resulting products in the same report.

The following tables give the duty of water under the Gage Canal as a whole for the year 1900–1901, and the duty of water in the three districts and for the canal as a whole for the three years during which measurements have been made:

Water used under Gage Canal November 1, 1900, to October 31, 1901.

Month.	Miner's inches.	Acre-feet.	Month.	Miner's inches.	Acre-feet.
November	830	987.77	June	1,389	1,653.05
December	360	442.71	July	1,309	1,609.77
January	405	498.06	August	1,452	1,785.68
February	230	255.64	September	1,424	1,684.70
March	876	1,077.25	October	1,283	1,577.79
April	1,385	1,648.29			
May	1,420	1,746.87	Year	1,084	14,967.53

Duty of water under Gage Canal November 1, 1900, to October 31, 1901.

Area irrigated	acres..	7,501.84
Water used	acre-feet..	14,967.53
Depth of water used in irrigation	feet..	2.00
Depth of rainfall	foot..	.67
Total depth of water received by land	feet..	2.67

Duty of water under Gage Canal, 1898–1901.

District and year.	Area.	Water used.	Depth of irrigation.	Depth of irrigation and rainfall.
District No. 1:	*Acres.*	*Acre-feet.*	*Feet.*	*Feet.*
1898–1899	3,595	8,330.46	2.32	2.79
1899–1900	3,614	8,779.64	2.43	2.87
1900–1901	3,614	7,478.78	2.07	2.74
District No. 2:				
1898–1899	2,871	6,407.80	2.23	2.71
1899–1900	3,237.84	6,855.71	2.12	2.56
1900–1901	3,237.84	6,584.44	2.03	2.70
District No. 3:				
1898–1899	530	943.55	1.78	2.26
1899–1900	650	1,059.89	1.63	2.07
1900–1901	650	904.31	1.39	2.06
Canal as a whole:				
1898–1899	6,996	15,681.84	2.24	2.72
1899–1900	7,501.84	16,695.24	2.23	2.67
1900–1901	7,501.84	14,967.53	2	2.67

The average monthly flow during the irrigating months from April to September, inclusive, has been greater during last season than for the same months of the season previous, while the average for the whole year has been considerably less than for the year previous. This is accounted for by the greater rainfall during the winter months, the total for last season being 8.04 inches, compared with the 5.26 inches for the previous year. This greater rainfall was very evenly distributed over the months of November, January, and February, and in consequence the wells were capped for considerable periods in the months referred to and up to the middle of March. Generally the service during the year was satisfactory, notwithstanding an interruption of about three weeks in consequence of the largest pumping installation being destroyed by fire, thus reducing the total supply to the extent of about 150 inches for the time being.

PROFITS.

The following table gives a general statement of capital investment, maintenance, and product of an acre of navel oranges for a series of years:

Statement of expenses and returns for 1 acre of navel oranges.

Year.	Cost of 1 acre land.	Planting to trees.	Cultivation and irrigation.	Fertilizers.	Canal dues.	Taxes.	Yearly outlay.	Interest.	Total investment.	Product.
1	$400	$120	$18.00	....	$2.50	$4.50	$545.00	$43.60	$588.60	....
2	....	....	18.00	....	2.50	4.50	25.00	49.08	662.68	....
3	....	....	18.00	$5.00	2.50	4.50	30.00	52.67	745.35	....
4	....	....	18.00	8.00	2.50	4.50	33.00	62.26	793.61	$47
5	....	....	20.00	10.00	2.50	5.00	37.50	66.48	762.59	135
6	....	....	20.00	12.00	2.50	5.50	40.00	64.20	666.79	200
7	....	....	20.00	15.00	2.50	6.00	43.50	56.82	542.11	225
8	....	....	20.00	15.00	2.50	7.00	44.50	45.95	382.56	250
9	....	....	30.00	20.00	4.50	8.00	62.50	35.60	205.66	275
10	....	....	30.00	20.00	4.50	8.50	63.00	21.49	....	290

FIG. 1.—STOP IN GAGE CANAL.

FIG. 2.—LATERAL PIPE AND VALVE, GAGE CANAL.

FIG. 1.—HYDRANT BOX IN POSITION.

FIG. 2.—HYDRANT BOX DISCHARGING WATER OVER WEIR.

FIG. 1.—HYDRANT BOX AND CEMENT FLUME DISCHARGING WATER.

FIG. 2.—CEMENT FLUME AND FURROWS IN ORCHARD.

Fig. 1.

VIEWS OF SANTA ANA VALLEY.

Fig. 2.

FIG. 1.—GAGE CANAL NEAR THE HEAD GATE.

FIG. 2.—GAGE CANAL 1 MILE BELOW HEAD GATE.

FIG. 1.—GAGE CANAL PASSING OUT OF TUNNEL NO. 2.

FIG. 2.—GAGE CANAL AT FLUME NO. 2.

In explanation of the table it will be understood that the cost of land at the sum per acre shown includes the ownership of a water right on the basis of 1 inch to 5 acres. It will be further understood that all expenditure during the first three years has been charged with interest at 8 per cent, and this interest added to principal amount each year. The same process is carried out in the succeeding years; but the product in packed boxes per acre, valued at $1 per box, is deducted from the total investment as it appears for each following year. This system, carried out to the end of the term of ten years, results in the products, as above valued, liquidating all expenditures on capital account, together with the interest compounded for the whole time.

SYSTEM OF DISTRIBUTION.

On the line of canal at points where it is intersected by streets, usually at intervals of one-fourth of a mile, masonry bulkheads (Pl. XVI, fig. 1) are built for the diversion and measurement of the water into the different main pipe lines laid in the streets. The diversion of the water is effected by means of bulkhead boards inserted across the flow of water in the canal, and kept in place by grooves in the masonry of the bulkhead. The water, being thus obstructed, passes from the canal through a pipe into the bottom of a measuring box situated in the bulkhead, and then up over a weir, thus registering the total amount of water used for irrigation of the lands depending on that particular pipe for their supply.

At distances of about 650 feet lateral pipe lines are inserted into the mains (these points being opposite the upper line of each subdivision fronting the street), and thence are carried to the highest point of each subdivision, except where more than one subdivision can be conveniently irrigated from one hydrant. At the end of each lateral a hydrant and measuring box are attached, and the amount of water used for the irrigation of each parcel of land is measured as it discharges into the flume over a weir built in the measuring box for that purpose.

The system of distribution is shown in the accompanying plates. Pl. XVI, fig. 1, shows the "stops" in the line of the canal at intervals of about one-fourth mile for the diversion of water from the main pipe lines in the streets. Pl. XVI, fig. 2, shows the lateral pipe from the main in the street to each 10-acre lot. The pipe terminates in a "low-down" valve or hydrant, inclosed in a hydrant box made of cement-concrete. The box is shown off of its foundation to make the valve visible. Pl. XVII, fig. 1, shows the hydrant box in position with reference to the lateral pipe and inclosed valve, and shows the opening in the side of the box for discharging and measuring the water. Pl. XVII, fig. 2, shows the hydrant box and connecting flume, also the discharge

of water over the measuring weir from the hydrant box. Pl. XVIII, fig. 1, shows the cement flume carrying water from the hydrant box for a distance of 660 feet along the higher boundary line of a 10-acre lot. From this flume water is discharged in small streams at distances of about 4 feet into furrows between rows of trees. Pl. XVIII, fig. 2, shows furrows between the trees with the water flowing in them.

CEMENT LINING OF GAGE CANAL.[a]

With reference to the general conditions existing prior to the improvements being undertaken, and the reasons for making them, you will please note the following particulars:

First. The first 12 miles of the canal was so far completed at the end of the year 1886 that some water was passed through it, with more or less difficulty. This first section contains all the more difficult engineering problems, as the grade of channel had to pass from the lower "river-bottom lands" to the higher "mesa" lands by following the serrated face of the escarpment joining these different levels. Along this "face" the channel—in parts—was open "side-hill" cuts, short and long tunnels, short fills, and flumes on trestlework of wood.

The character of the materials passed through, in excavating the tunnels, was such that the sides and bottom of the channel had to be lined with cement concrete, and the roof strongly timbered. All other parts of the channel, at this time, were left in clay formation.

During the years 1887 and 1888 the remaining 8 miles of canal were constructed, including several "fills" and four additional flumes.

Second. From the year 1886 to 1890 the first section of canal was used continuously, and carrying about 700 inches of water. The lower section was used very little; but the water was run through it for the purpose of consolidation, and to reveal gopher holes and other weak spots.

During this short interval (three years) we had many very serious breaks in the channel. One of the most important occurred on the face of the escarpment, above referred to, in a side-hill cut, where the water found its way through the outer bank, and before the action of the water could be stopped 50 feet of the bank was cut to a depth of 30 feet; indeed, to the very bottom of the bluff. This one break alone interrupted the general irrigation for about six days; and besides working night and day with "relays" of six teams, we had to pay a considerable sum on account of damage to neighboring property.

Generally we found that all fills were, under the action of the water, subject to great distortion and settlement. Even certain parts following natural grades were subject to settlement, due, we think, to bur-

[a]This discussion of the lining of the Gage Canal was supplied by Mr. Irving at the request of this Office, because of the frequent inquiries received for information on the lining of canals.

rowing animals having perforated the adjacent territory. In fact, we find the same thing occurring when irrigating lands for the first time—quite considerable areas will settle below the general level. The large fills were a constant source of anxiety because of the settlement and the burrowing of gophers, and the serious consequences following a rupture of the banks.

Another source of trouble was the rapid decay of the woodwork at the ends of flumes where it came in contact with the earth.

Third. We found that in consequence of the rapid growth of vegetable matter on the banks and bottom of channel the capacity of the canal was so much reduced that one-fourth the calculated volume of water could not be safely carried through it.

Fourth. While the question of seepage is always a most important factor to be fully considered in the designing of irrigating channels, the real losses of water from this cause will vary with the character of the soil through which the channel passes. In our case, after the first year the loss was not greater than 15 per cent for the first section, nor more than 25 per cent for the whole length of over 20 miles of channel. Even this loss was gradually being reduced by the saturation of the adjacent territory before the improvements were commenced.

Fifth. When the channel is carrying 1,500 inches of water (the present amount), we estimate the losses from evaporation to be about 1 per cent.

Sixth. In addition to all the physical reasons we had for improving the Gage Canal there was a legal one arising out of the terms of the contracts Mr. Gage made with the first purchasers of water under the flow of the first section of canal, where it was provided that the canal would be cemented within a certain number of years wherever required to prevent the seepage of water therefrom. While there might be a question as to the real legal responsibility of doing more than had already been done in cementing all the tunnels, it entered as a factor in determining to cement this particular section throughout.

The above are the conditions prevailing in the year 1890, when the Gage interests in the canal passed to the Riverside Trust Company, and when, among other projected improvements, the reconstruction of the unimproved parts of the canal was determined on and the details worked out as provided in the accompanying plans and specifications.

After fully considering the whole problem, and having a due regard to the vital factor of cost as between many possible methods of treatment, it was decided to take in some measure the risk of an experiment in applying cement mortar to the clay banks and bottom of water channels.

To make this clear it will be understood that all fills were lined with masonry, as provided in class of work "B."

All sidehill cuts where the outer bank and bottom was "made earth" the same lining was applied and the inner bank treated with class of work "C." In sidehill work where the bottom was in "cut" the outer bank only was lined with masonry and inner bank and bottom lined with "C."

In all cases where grade was found by following the natural surfaces and where generally the upper bank was in full cut and lower bank about one-half cut and remainder "fill," the whole interior surfaces were coated with mortar, as provided in class of work "C."

As this latter condition was the most general, after deducting the tunnels and flumes, the importance of it as to the factor of cost will at once be made evident, and it is to this class of work only that the term "experimental" will be applied.

It will be noted from the contracts that while the masonry lining cost $2 per foot linear of canal, the plastered work, "C," cost only 75 cents per foot.

Now, as to the results: After a test of ten years, it can be fairly said that the experimental part of the improvements has more than justified our expectations. It is very true, of course, that this thin lining is subject to rupture from causes which would not affect the thicker portions; but, as a whole, and in view of the cost as compared to the other, it has served its purpose very well. During the last four years, because of the arid conditions, we had to run irrigation water during the entire season of each year, consequently we were unable to make any repairs to the cementing. This year, however, we made a thorough repair of all the sections, except a small portion at the upper end, and the total cost was less than $500, less than the half of 1 per cent of the capital cost in four years.

An improvement of this mode of treatment, which was adopted in making the recent repairs, is to form a series of ribs on the back of the cement lining by simply indenting the clay surfaces before the cement coating is applied at regular intervals and in both directions, horizontal and perpendicular or diagonally. The indentations can readily be made with a "form" while the clay faces are moist, which they have to be at the time of the application of the coating.

The following are extracts from the specifications and contracts for the lining of the canal:

The contractor shall remove from off the banks of canal all present deposits of matter which is of a vegetable character, and no such matter will be allowed to be incorporated in any "filling" that may be required on said canal, such filling to be of pure clay, or soil free from vegetable compound.

Cutting and filling.—The contractors shall prepare all the sloping banks and bottom of canal to the alignments, slopes, and grades determined and fixed by the engineer; by removing all the surplus materials, and by depositing well-tamped clay of the proper consistency wherever required to bring all the surfaces to the alignments, slopes, and grades as above specified.

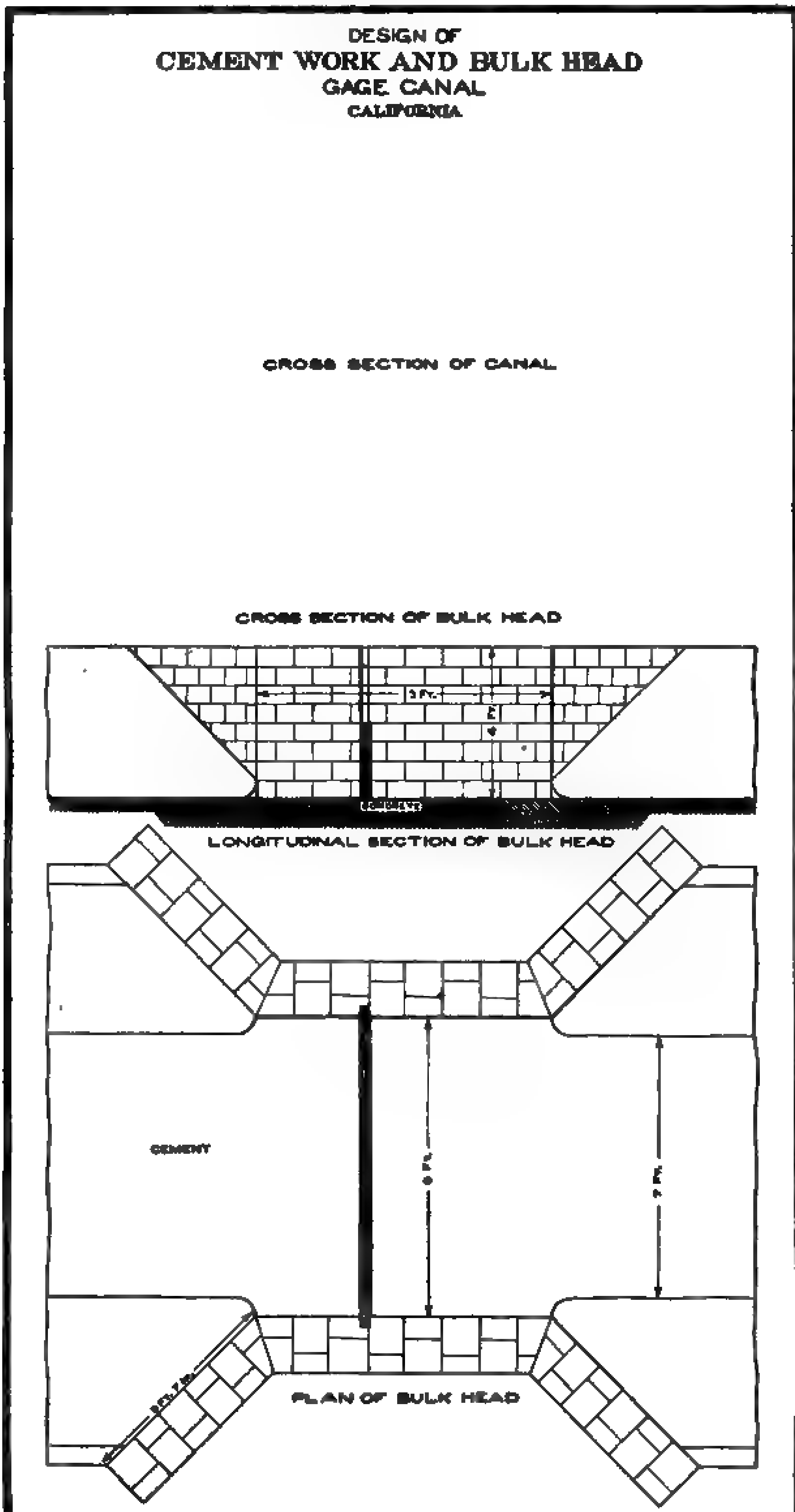

FIG. 5.—Design of cement work and bulkhead, Gage Canal, California.

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Borrows.—"Borrows" of clay, when required, may be made from the outer slopes of canal banks, or other adjacent territory within the "right of way" of canal; but in such a way as shall not impair the strength of the banks or destroy the general uniformity of the ground from which the "borrows" are made.

Moistening surfaces.—All the surfaces above referred to, to be properly moistened immediately previous to the application of all coatings of cement, or at other times when such is necessary to the proper consolidation of the clay fillings.

General.—All masonry, walling, concrete, and plastering to be of the very best description consistent with the following detailed particulars, and to be placed in position and thoroughly compacted together by competent workmen who have sufficient experience in similar work to insure the best results under the several conditions specified. As certain portions of the canal will require to be coated with different kinds of materials, and materials in different proportions, they shall be described and known by the letters A, B, C, etc., following. (Fig. 5.)

"A," masonry for retaining walls.—Excavations shall be made by the contractors wherever required for retaining walls at end of flumes, and for abutments of bridges, of such dimensions as shall be determined from time to time by the engineer in charge. The said retaining walls and abutments shall be constructed in accordance with the drawings herewith attached, and of the best masonry, composed of good large building stone, generally not less than 2 feet in cubic contents, thoroughly bedded in cement mortar, composed of one part Portland cement, three parts fat lime, and twenty parts clean, sharp sand, and the whole mass to be thoroughly bonded in all parts; and all interspaces filled with hand-packed stone laid in mortar.

All surfaces exposed to the action of water to be coated with mortar to the depth of three-eighths of an inch, composed of one part Portland cement and three parts clean, sharp sand. All other surfaces to be thoroughly flush pointed in the joints with similar mortar. All connections between stone and wood, or between other materials, to be made thoroughly water-tight. Bed all plates, sills, or other materials required in the construction of said walls and abutments that may be ordered from time to time by the engineer in charge or by his representative. When the walls and abutments have been fully completed, inspected by the engineer in charge, and accepted by him as perfect, the contractors shall then refill all the spaces around the foundations with well-pounded clay to the line of the adjacent surfaces, and spread any surplus materials in a uniform manner over the adjacent territory.

"B," masonry for walling.—Masonry, composed of good building stone, will be laid to certain parts of the sloping sides of canal banks to a thickness of 5 to 6 inches, thoroughly bonded in all parts, and laid in mortar, as specified for "A." All surface joints to be cut out during the progress of building to permit of "key" to the plaster coating to be applied subsequently. Plaster all the external surfaces of said walling which comes in contact with the flowing water to a thickness of three-eighths of an inch and with mortar of the quality provided for plastering surfaces in section "A," the said mortar to be thoroughly consolidated on the walled surfaces and "troweled" hard and even.

"C," plastered work.—Plaster composed of one part best Portland cement and four parts clean river sand of an uniform texture will be laid to certain parts of the sloping banks and bottom of canal, and thoroughly compacted and troweled hard and firm to the alignments and grades, and to a thickness of three-fourths of an inch, finished.

"D," bulkheads.—Construct the "bulkheads" wherever designated by the engineer, together with all the connected works, as shown, and in accordance with the drawings related thereto. The excavations for said bulkheads may vary in depth, depending on the nature of the soil, but in all cases the depth shall be determined by the engineer, the depth shown on the drawings to be followed when the conditions

are suitable. The portions on the drawings as being constructed of stone shall be built of the best quality of building stone (granite), thoroughly bedded in mortar, as specified under section "A," and the whole well bonded and built true to alignments and positions designated on the ground. The portions shown as being constructed of brick shall be built of the best hard-burned brick, laid in plastering mortar, as described in section "A," for plastered surfaces, and well bonded in all parts. Build into said bulkheads all "fittings" of wood or iron required for weirs, valves, covers, and pipes, as shown on drawings. Plaster all the surfaces of stone and brick exposed to the action of water to the thickness of three-eighths of an inch with cement mortar, well troweled, hard, and even, and of the quality described under section "A" for similar work. The trust company will provide all pipes, valves, weirs, bolts, and woodwork in connection with said bulkheads, and the contractors shall build them into the work when required.

Class of work.—The engineer in charge reserves to himself the right to adopt any or a part of any of the above-described kinds of work in the lining of canal, and shall from time to time determine the kinds of work and the sections or parts of the canal to which they will be applied.

Price per cubic yard of masonry for retaining walls to flumes and foundations to bridges, with the class of work described in section "A," $7 per cubic yard.

Price per foot, linear, of canal, for walling both sides and bottom of canal with the class of work described in section "B," $2 per linear foot of canal.

Price per foot, linear, of canal, for walling both sides of canal with the class of work described in section "B," and the bottom of canal with the class of work described in section "C," $1.48 per linear foot of canal.

Price per foot, linear, of canal, for walling one side of canal with the class of work described in section "B," and one side and bottom with the class of work described in section "C," $1.13 per linear foot of canal.

Price per foot, linear, of canal, for plastering both sides and bottom of canal with the class of work described in section "C," 75 cents.

Price each for bulkheads and discharge basins as described in section "D," $78.80.

DUTY OF WATER IN TULE RIVER BASIN, CALIFORNIA.

By A. E. CHANDLER, *Special Agent.*

TULE RIVER.

The three branches of the Tule River rise on the western slope of the Sierras, at an elevation of from 6,000 to 7,000 feet. The North Fork joins the Middle Fork about 16 miles above Porterville, which is situated on the eastern edge of the San Joaquin Valley and is the principal town of the Tule River Basin. (Map, Pl. XXII.) From the junction the stream flows 10 miles in a southwesterly direction to its confluence with the South Fork. Thence the general course of the river is due west to Lake Tulare. The limits of this lake are somewhat elastic. At the highest known stage, in 1861–62, its surface area was 800 square miles, while in the summer of 1900 it was entirely dry. During June, 1901, freshets on the Kings and Kaweah rivers covered

half a dozen townships on the old lake bottom, but the area had very much diminished by the end of the year.

Pl. XXIII shows Tule River 20 miles above Porterville.

PRECIPITATION.

Unfortunately no records of precipitation have been kept in the Tule Basin outside of Porterville. The record kept by the Southern Pacific Railroad agent at Porterville for the last thirteen years is given below. (See diagram, fig. 6.) The elevation of Porterville is 461 feet.

Precipitation at Porterville, Cal., 1889–1901.

Year.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Annual.
1889	0.82	0.18	1.26	0.42	0.89	Trace	0.00	Trace	0.00	3.41	0.45	3.28	10.66
1890	3.43	.49	1.30	.12	.20	0.00	.00	0.15	.00	.00	.40	2.78	8.87
1891	.36	2.43	.71	1.14	.29	.00	.00	.00	.01	.00	.36	3.38	8.68
1892	.26	1.33	2.21	.16	.65	.22	.00	.00	.00	.17	.54	2.43	7.97
1893	.83	1.85	3.68	.27	.00	.00	.00	.00	.00	.00	.07	.61	7.31
1894	1.52	.83	.71	.32	.42	1.09	.00	.00	.43	.15	.04	3.13	8.64
1895	3.82	1.54	1.10	.41	.35	.00	.00	.00	Trace	.28	1.71	.51	9.67
1896	1.61	Trace	.67	1.13	.13	.00	.69	.00	Trace	.65	.94	.93	6.75
1897	1.96	2.46	2.00	.30	.42	.00	.00	.00	.00	1.19	.50	.89	9.72
1898	.75	1.55	.08	Trace	.55	.00	.00	.00	2.10	Trace	.27	.35	5.65
1899	1.01	.17	2.02	.19	.10	.85	.00	Trace	.00	1.08	.88	.91	7.21
1900	.97	.16	.89	1.94	2.41	.00	Trace	.00	Trace	.04	3.44	.30	10.15
1901	2.74	1.78	.80	2.19	1.97	.00	.00	Trace	.41	.45	.26	Trace	10.10
Mean	1.54	1.14	1.30	.66	.64	.17	.05	.01	.23	.57	.76	1.50	8.57

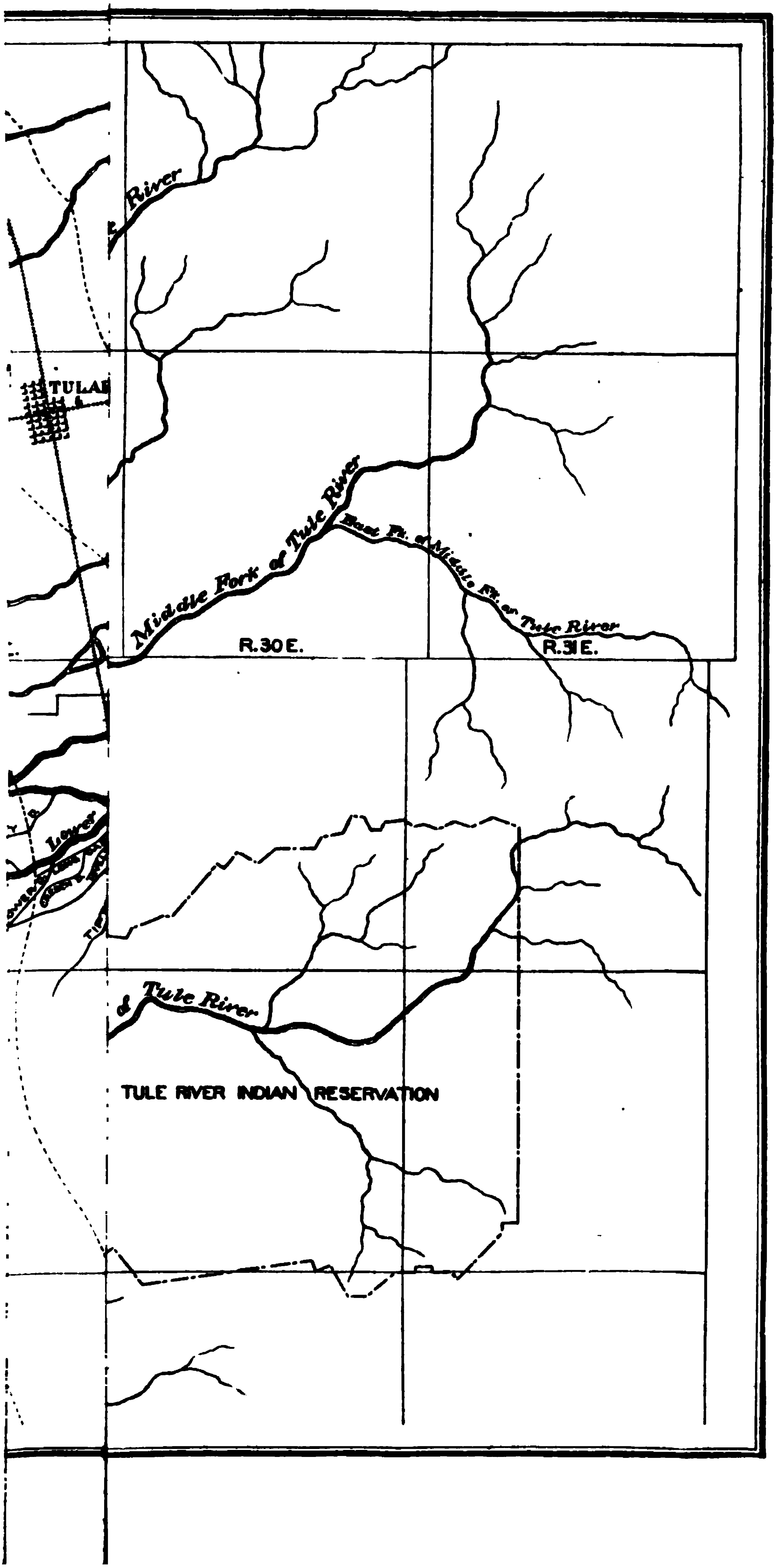
The average annual precipitation for the thirteen years is shown to be 8.57 inches, with a minimum of 5.65 inches in 1898 and a maximum of 10.66 inches in 1889. The rainfall during the past year, 1901, was about 18 per cent greater than the average.

STREAM MEASUREMENTS.

The California State engineer made an estimate of the discharge of Tule River from gauge-rod readings taken 5 miles above Porterville for the period from November, 1878, to October, 1884. There is no record of rainfall in the Tule Basin for the same time, but that of Lewis Valley, 8 miles north of Porterville, is a good substitute. From it we learn that the annual rainfall was as given below:

Rainfall, Lewis Valley, 1879–1883.

	Inches.
1879	8.08
1880	14.16
1881	6.37
1882	7.42
1883	5.34
Mean	8.27


River
TULAR
Middle Fork of Tule River
East Fk. of Middle Fk. of Tule River
R.30 E.
R.31 E.
Lower
of Tule River
TULE RIVER INDIAN RESERVATION

TULE RIVER 20 MILES ABOVE PORTERVILLE.

Diagram showing rainfall, Porterville, Cal., 1889–1901.

Fig. 6.—Rainfall diagram, Porterville, Cal.

The drainage area of Tule River is 437 square miles, and the discharge of the stream for the period during which records were kept was as follows:

Estimated discharge of Tule River at Porterville, Cal., 1878-1884.

Month.	1879.	1880.	1881.	1882.	1883.	1884.	Mean.
	Cu. ft. per second.	Cu. ft. per second.	Cu. ft. per second.	Cu. ft. per second.	Cu. ft. per second.	Cu. ft. per second.	Cu. ft. per second.
January	57	577	219	87	87	262	215
February	87	1,040	437	109	87	1,748	585
March	61	1,079	437	306	437	1,311	605
April	118	1,289	874	660	656	874	745
May	105	1,040	874	1,748	874	2,185	1,138
June	350	721	437	660	874	3,059	1,017
July	35	350	219	437	350	2,622	669
August	26	87	175	131	87	874	230
September	26	44	87	66	66	350	106
October	74	44	66	44	44	175	75
November	140	87	57	66	44	....	79
December	271	219	66	66	66	....	138
Mean	112	548	329	365	306	....	466

No measurements were taken since 1884 until last summer. The U. S. Geological Survey then established a gauging station on Tule River about 8 miles above Porterville. This station is above the point where the South Fork enters the main stream. It had to be so placed in order to obtain the record of summer flow, as the Pioneer Canal, which diverts almost the entire stream in the drier months, is also above the South Fork. Furthermore, the South Fork is generally dry during the summer, its water being entirely appropriated by the South Tule and King ditches. The daily discharge for 1901, beginning with May 1, is as follows:

Daily discharge of Tule River, 1901.

Day.	May.	June.	July.	August.	September.	October.	November.	December.
	Cu. ft. per second.	Cu. ft. per second.	Cu. ft. per second.	Cu. ft. per second.	Cu. ft. per second.	Cu. ft. per second.	Cu. ft. per second.	Cu. ft. per second.
1	407.37	407.37	125.54	29.74	18.15	21.17	44.87	57.98
2	407.37	407.37	117.97	18.15	18.15	21.17	44.87	57.98
3	378.63	364.51	108.90	18.15	18.15	21.17	38.82	57.98
4	350.39	337.29	108.90	23.19	18.15	23.19	38.82	50.92
5	350.39	350.40	92.77	23.19	18.15	23.19	38.82	50.92
6	378.63	323.68	77.64	21.17	18.15	23.19	38.82	50.92
7	407.37	297.46	71.09	21.18	18.15	21.17	38.82	57.98
8	407.37	350.40	71.09	21.18	18.15	21.17	34.79	57.98
9	407.37	323.68	71.09	18.15	16.14	18.15	34.79	64.03
10	514.25	272.75	64.03	18.15	16.13	18.15	38.82	64.03
11	439.13	237.46	64.03	18.15	14.12	18.15	50.92	64.03
12	474.42	248.55	64.03	18.15	14.12	21.18	50.92	57.98
13	474.42	248.55	57.98	18.15	11.09	21.18	44.87	50.92
14	439.13	225.87	57.98	18.15	10.08	21.18	44.87	50.92
15	439.13	203.68	50.92	18.15	10.08	21.18	44.87	50.92
16	439.13	182.51	50.92	18.15	10.08	18.15	44.87	50.92
17	457.28	193.60	50.92	18.15	11.09	18.15	38.82	50.92
18	439.13	214.77	50.92	18.15	13.11	18.15	38.82	50.92
19	423.50	203.68	50.92	18.15	16.13	18.15	38.82	50.92
20	407.37	193.60	50.92	18.15	16.13	21.18	38.82	50.92
21	378.63	182.51	44.87	18.15	16.13	21.18	38.82	44.87
22	337.28	182.51	44.87	18.15	16.13	21.18	38.82	44.87
23	323.67	182.51	44.87	18.15	16.13	18.15	38.82	44.87
24	297.46	172.93	44.87	18.15	18.15	18.15	38.82	38.82
25	873.72	162.84	44.87	18.15	23.19	18.15	38.82	38.82
26	378.63	162.84	38.82	18.15	23.19	18.15	38.82	38.82
27	407.36	162.84	34.79	18.15	21.18	77.64	38.82	38.82
28	407.37	125.54	29.75	18.15	21.18	108.90	44.87	38.82
29	378.63	134.61	29.75	18.15	21.18	85.70	57.98	38.82
30	378.63	134.61	29.74	18.15	21.18	57.98	71.09	38.82
31	350.39	....	29.74	18.15	....	44.87	....	38.82
Average	417.86	239.70	60.50	19.14	16.70	28.98	42.48	49.85

TULE RIVER 6 MILES BELOW PORTERVILLE, JUNE 26, 1901.

From a comparison of the above tables of discharge it would seem that the State engineer's estimate was entirely too high. The rainfall for the year 1901 is considerably larger than the mean for the years 1879–1883, while the flow of the stream during the time when measurements were made in 1901 is only about one-fourth of the mean discharge for the same months from 1879 to 1883. The discharges given by the United States Geological Survey check well with measurements made by our field party and must be approximately correct.

In starting the work on Tule River we had hoped to establish gauging stations opposite Porterville and at points lower on the river in order to study the loss and gain in the natural channel. The wide bed of shifting sand and the small amount of water reaching the points, however, rendered the plan unpractical. A number of measurements taken during the season, which disclose something of the nature of the stream, are as follows:

Measurements of discharge of Tule River, 1901.

No.	Date.	Place of measurement.	Length of section.	Discharge.		Gain (+) or loss (−).
			Miles.	*Cubic feet per second.*		*Cubic feet per sec.*
1	May 23	Below Poplar Ditch wasteway			262.7	
2	....do...	Intermediate ditches		27.2	240.8	− 21.9
3	....do...	4¼ miles below No. 1		213.6		
4	June 24	Lower Tule River, near mouth			198.2	
5	June 26	1 mile below Pioneer Ditch	4		149.3	
6	....do...	Intermediate ditches		78.1	140.8	− 8.5
7	....do...	Below Vandalia Ditch		62.7		
8	June 28	Globe (14 miles above Porterville)			164.6	
9	....do...	Intermediate ditches		11.0	158.6	− 6.0
10	....do...	6 miles below Globe		147.6		
11	July 29	Below Pioneer Ditch	3.5		19.8	+ 3.0
12	....do...	Above Plano Ditch			22.8	
13	....do...	Below Plano Ditch	3.25		2.2	+ 8.4
14	....do...	Plano Bridge (opposite Porterville)			10.6	
15	Aug. 8	Campbells Island (12 miles above Porterville)	5		18.6	
16	....do...	Intermediate ditches		7.9	25.4	+ 6.8
17	....do...	Above Pioneer Ditch		17.5		
18	....do...	Below Plano Ditch	3.25		0.8	+ 8.3
19	....do...	Plano Bridge			9.1	

The first three measurements, taken on May 23, show a considerable loss from a point opposite Porterville down the stream. This fact is patent even to the casual observer later in the season when the stream is lower.

Measurement No. 4 shows the amount of water that reached the Lower Tule River through Elk Bayou, a branch of Kaweah River. On the same date the upper river was practically dry at Rockford Bridge, 6 miles below Porterville. (Pl. XXIV.)

The measurements of June 26 indicate a small loss between the Pioneer and Vandalia ditches; but the first two of July 29 show a gain between the Pioneer and Plano ditches. This last fact is borne out by the experience of the Pioneer Canal officials. That there is a decided gain between the Plano Ditch and Plano Bridge is clearly shown by measurements Nos. 13 and 14 and 18 and 19.

Measurements Nos. 5, 6, and 7 imply a small loss on the upper stream, while Nos. 15, 16, and 17 indicate that almost all the water diverted returned to the river.

We may summarize by saying that little or no loss exists above the Pioneer Canal; that there is a gain by seepage from the bordering irrigated lands between the Pioneer Canal and Porterville, and that below Porterville the water is gradually lost in the sandy bed.

STORAGE POSSIBILITIES.

No good reservoir site exists on or near Tule River. The branches of the Middle Fork rise in so-called "meadows," which are often referred to as possible impounding sites. The most promising of these, Summit Meadow, or Summit Lake, was surveyed in 1896 at the expense of a resident of Porterville. The lake is 27 miles from Porterville and over 6,000 feet higher, and its undesirability as a storage reservoir is apparent from the results of the survey. The lake has a drainage area of but 106 acres. The proposed dam was to be 20 feet high and 220 feet long on top. The lake has an area of 5 acres, and the proposed reservoir was to cover 12 acres. The lake was to be drained 10 feet below its present level. This would give a storage capacity of 25 acre-feet for the lake and 130 acre-feet for the reservoir. a total of 155 acre-feet.

It has also been suggested to submerge part of Pleasant Valley, but from the general topography of the country it appears that the amount stored would not justify the expense of storing it.

A few farmers under the South Tule Independent Ditch have had in mind the damming of the South Fork about half a mile below the Tule River Indian Reservation. Here again a survey would prove the plan untenable. The cost of a dam across the main channel would be excessive when compared with the small impounding area behind it.

DIVERSIONS FROM TULE RIVER.

There are some fifty ditches taking water from Tule River, most of which are discussed in the following pages. Since the drying up of Tulare Lake, two large ditches have been constructed to irrigate the former bed of the lake. (Pl. XXV.) Both of these, the Angiola Canal and the Lower Tule River Canal, get their supply from Elk Bayou at all times except during the flood seasons on the Tule River.

The Angiola Canal heads on the south bank of Tule River (or Elk Bayou) 12 miles west of Tipton. It was constructed in 1897 at a cost of $4,000 and is owned by a corporation having a capital stock of $100,000, divided into 1,000 shares. The canal is 7 miles long and has a width of 30 feet, a depth of 3 feet in excavation and 4 feet in

DIVERTING WEIR, TULARE LAKE CANAL.

embankment, and a grade of 2 feet per mile. During 1901 about 10,000 acres of wheat and barley were irrigated, most of the land being flooded in 40-acre checks. The company charges 50 cents per acre per season for delivering water, and crops are generally irrigated but once.

The Lower Tule River Canal is 1 mile west of the Angiola Canal. It was constructed in the fall of 1896 at a cost of about $3,000. There are 4½ miles of main canal and 12 miles of laterals. The canal has a bed width of 45 feet and the laterals from 12 to 20 feet. The depth of the main canal is 5 feet and that of the laterals 3 to 4 feet. The grade is 1 foot to the mile. Four thousand acres of wheat, alfalfa, and wild feed were flooded in 1901.

INVESTIGATIONS OF 1901.

It was not definitely decided to make a study of the duty of water in the Tule River Basin until April. This was too late to get a complete record for the season, but an effort was made to register the amount of water carried by all of the principal ditches for the time remaining. The plan was to place a gauge rod in a straight section of each ditch near its head, and then to rate this section by current meter measurements. The great majority of head gates, however, are far from any habitation, and the main ditch is generally cut by laterals before a point can be reached where a rod might be read regularly. For these reasons we have not a record for all of the visited ditches using water after May 1.

During the three years preceding, few of the ditches in the vicinity of Tipton were able to get water even in the winter; but in 1901 the supply was so unusually good that some irrigating was done as early as in June. This report will deal only with the ditches above and including the Stockton Ditch, the head of which is about 6 miles below Porterville. This may be considered the western limit of the zone of late spring irrigation, it being but a chance that the lower ditches will get water after April.

SMALL DITCHES.

Before passing to the more important work of the investigation, mention will be made of the small private ditches which diverted water from the river above Stockton Ditch during 1901. The principal items in regard to them are tabulated below. As they are very irregular in width, depth, and grade, none have been specified. Most of them will average 3 feet in width and 2 feet in depth.

Small diversions from Tule River above Stockton Ditch.

Ditch.	Date of construction.	Location of head.	Length.	Acreage irrigated.				Measurement.	
				Orchard.	Vegetables.	Alfalfa.	Grain.	Date.	Discharge.
South side of main stream:			*Miles.*					1901.	*Cu. ft. per sec.*
Marksbury	....	W. line sec. 17, T. 21 S., R. 29 E.	1	2	3	50	....	Aug. 3	2.4
Old Vincent	1869	Middle sec. 17, T. 21 S., R. 29 E.	1¼	....	5	45	....	Aug. 2	3.0
A. P. Osborn	1888	W. line sec. 15, T. 21 S., R. 29 E.	1¼	....	....	20	....	....	....
Crabtree & Osborn	1874	NE. ¼ sec. 14, T. 21 S., R. 29 E.	2	2	....	6	....	....	....
Osborn & Graham	1874	SW. ¼ sec. 2, T. 21 S., R. 29 E.	7	20	....	60	....	July 30	3.1
North side of main stream:									
Burton	1863	NW. ¼ sec. 35, T. 21 S., R. 27 E.	2½	....	[a]30	70	....	....	....
Wallace	....	SE. ¼ sec. 31, T. 21 S., R. 28 E.	1¼	....	....	25	50	....	....
Traylor	....	NW. ¼ sec. 35, T. 21 S., R. 28 E.	2	3	....	....	40	July 19	1.6
O. A. Wilcox	1875	Middle sec. 24, T. 21 S., R. 28 E.	3	6	....	20	70	July 29	2.8
Jos. Lewis[b]	1889	Middle sec. 18, T. 21 S., R. 29 E.	½	7	....	....	....	...do....	.3
Walker	1871	Middle sec. 2, T. 21 S., R. 29 E.	1	10	5	60	....	....	.5
North side of Middle Tule:									
Mount Whitney	1893	SE. ¼ sec. 25, T. 20 S., R. 29 E.	5	....	....	....	....	July 29	2.7
G. W. Duncan	....	NW. ¼ sec. 6, T. 21 S., R. 30 E.	2	20	....	....	....	...do....	4.2
Aiken	1884	NE. ¼ sec. 32, T. 20 S., R. 30 E.	1¼	12	3	15	....	...do....	.4

[a] Corn. [b] Water raised 30 feet into a 7 by 8 inch flume by a wheel 37 feet in diameter.

STOCKTON DITCH.

There were about 350 acres of alfalfa, 25 acres of barley, and 20 acres of vineyard and orchard irrigated by the Stockton Ditch during 1901. Generally all irrigating must be done during the winter and early spring, as there is no available water in late spring and summer. During this season, however, the ditch was not dry until the middle of June. The following measurements were taken:

Discharge of Stockton Ditch.

	Cubic feet per second.
May 21	12.5
May 24	6.6
June 3	14.6
June 12	3.2

From gauge height records kept during May, it is estimated that 895 acre-feet entered the ditch. No record was kept in June, and, as nothing definite is known of the flow during the earlier months, no timate of the duty of water will be attempted. (See Pl. XXVI, 1.)

FIG. 1.—WING DAM, STOCKTON DITCH.

FIG. 2.—DIVERTING DAM, VANDALIA DITCH.

CALLISON SLOUGH.

As there are no homes near the head of Callison Slough, a gauge rod could not be favorably placed. The following measurements were taken near the head gate:

Discharge of Callison Slough.

	Cubic feet per second.
May 21	52.5
May 22	81.0
June 6	55.0
June 18	48.0

On June 6 a measurement taken 2½ miles below the head gave a result of 48 cubic feet per second. The loss by seepage in that distance was therefore 7 cubic feet per second, or 13 per cent of the flow at the head.

The exact acreage irrigated during 1901 could not be ascertained, the approximate figures being 50 acres of deciduous fruits and 850 acres of alfalfa and grain. Irrigating is commonly done during winter and early spring. There was water in the ditch this year until the last of June, but very little of it was used after the end of May.

TIPTON IRRIGATION DISTRICT CANAL.

From readings on a gauge rod placed in the Tipton Irrigation District Canal, close to its point of diversion from Callison Slough, it is estimated that there was a flow of 2,608 acre-feet from May 20 to June 23, 1901. The only use made of this water was to irrigate 150 acres of corn. This was the first use made of the ditch in five years, and in this time the gophers and squirrels had not been idle, as is shown by the seepage measurements recorded below. May 28, 1901, the discharge of the canal at the head was 75.5 cubic feet per second. A measurement 10 miles below showed a loss of 68 per cent of the flow at the head. Similar measurements made June 17, 1901, showed a discharge at the head of 48.7 cubic feet per second and a loss of 81 per cent in 12 miles. The district organization has been practically dead since 1895.

FINE DITCH.

The largest deciduous orchards in the Tule River Basin are under the Fine Ditch. There were 130 acres of barley, 445 acres of alfalfa, and 280 acres of deciduous trees irrigated during 1901, the season running from January to June. The measurements taken at the head of the ditch were as follows:

Discharge of Fine Ditch.

	Cubic feet per second.
May 24	21.2
June 17	27.8
June 18	31.9

On May 24 there was a discharge of 17.5 cubic feet per second 1½ miles below the head, and on June 18, 24.4 cubic feet per second at the same point. For this distance there was accordingly a loss of 17 per cent on the former date, and a loss of 24 per cent on the latter.

VANDALIA DITCH.

The natural losses from the Vandalia Ditch are by far the greatest along Tule River. The measurements showing the excessive seepage rate are as follows:

Seepage losses from Vandalia Ditch.

Date.	Discharge at head.	Distance.	Loss.
1901.	*Cu. ft. per sec.*	*Miles.*	*Per cent.*
June 18	16.0	2.0	92
June 21	16.0	2.0	89
July 1	10.2	1.5	96

The losses were so great that it was thought that a break existed somewhere in the ditch. On July 1, 1901, the ditch was followed throughout the length of 1½ miles and no loss other than that due to seepage and evaporation could be discovered. The ditch is an excavation in the sand of the first river bench.

During 1901 the irrigated acreage was made up of 30 acres of trees and 123 acres of alfalfa and grain. (See Pl. XXVI, fig. 2.)

HUBBS & MINER DITCH.

The Hubbs & Miner Ditch now takes its water through the Gilliam Ditch, on the condition that the Gilliam Ditch be allowed the full head two-sevenths of the time. The measurements made on the ditch were as follows: June 3, 5.4 cubic feet per second; June 6, 9.9 cubic feet per second. The acreage irrigated during 1901 comprised 464 acres of alfalfa, 454 acres of corn and barley, 22 acres of vegetables, and 46 acres of deciduous fruits.

PORTER SLOUGH.

Porter Slough formed part of the canal system of the Tule River Irrigation District. There has been no district organization for over three years, and the elaborate system of canals is practically not used. The Pioneer Canal occasionally diverted water from Porter Slough during 1901. Seepage measurements show a very small loss in the first few miles when the flow is large, but a considerable loss when it is sufficiently small to become but a thin sheet over the sand bottom. June 1, 1901, the canal was carrying at the head 97.6 cubic feet per second, and the loss in 2 miles was but 1.6 per cent. July 9, the discharge was 3.7 cubic feet per second, and the loss in 4 miles was 46 per cent.

FIG. 1.—MEASURING FLUME IN ORANGE GROVE.

FIG. 2.—MEASURING FLUME ON PIONEER DITCH.

POPLAR DITCH.

Daily readings on a gauge rod placed near the head gate of the Poplar Ditch, also known as the South Side Tule River Canal, were taken from April 11, 1901, until the supply ceased on July 6, 1901. The discharge in acre-feet follows:

Discharge of Poplar Ditch, April 11 to July 6, 1901.

Day.	April.	May.	June.	July.
	Acre-feet.	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*
1		37.69	184.46	58.51
2		27.37	184.46	78.35
3		43.64	168.60	50.58
4		32.13	168.60	50.58
5			168.60	9.32
6			137.85	1.98
7			120.99	
8		32.13	120.99	
9		9.32	105.12	
10		13.29	105.12	
11	120.99	13.29	90.84	
12	137.85	15.47	78.35	
13	153.72	15.47	168.60	
14	137.85	13.29	168.60	
15	137.85	13.29	137.85	
16	153.72	27.37	137.85	
17	168.60	37.69	120.99	
18	184.46	168.60	120.99	
19	184.46	184.46	105.12	
20	168.60	184.46	105.12	
21	153.72	198.94	90.84	
22	137.85	168.60	78.35	
23	137.85	168.60	67.44	
24	153.72	137.85	67.44	
25	137.85	137.85	90.84	
26	137.85	137.85	105.12	
27	153.72	168.60	67.44	
28	153.72	198.94	78.35	
29	168.60	198.94	78.35	
30	168.60	198.94	67.44	
31		184.46		
Total	3,051.58	2,768.58	3,490.71	249.32

This water was used to irrigate 3,000 acres, of which 1,200 were in alfalfa and the remainder in trees, summer crops, and pastures of native grass. The duty of water for the partial season is as follows:

Duty of water under Poplar Ditch, April 11 to July 6, 1901.

Area irrigated ... acres..	3,000.00
Wated used April 11 to July 6 ... acre-feet..	9,560.14
Depth of water used in irrigation ... feet..	3.19
Rainfall April 11 to July 6 ... foot..	.31
Total depth of water received by land ... feet..	3.50

The fact that the above summary shows only part of the water used must be emphasized. No definite data on the amount of irrigation earlier in the year could be obtained, and therefore no estimate for the preceding months is attempted. The figures given above are of importance in that they show the volume available during the later months of the irrigation season. One of the directors of the ditch company,

Mr. H. S. Bachman, is going to build a flume for the measurement of the water used on 25 acres of alfalfa during 1902. A register will be used for recording the water levels. The amount of water needed for alfalfa on average alluvial soil in this part of the country is as yet undetermined, so the study promises to be a very valuable one.

A number of measurements taken to determine the loss by evaporation and seepage are recorded below. The upper measurements of the first 4 sets were taken at the head. The first of the fifth set was taken 4 miles below the head; and the last set at the head of a lateral and 3 miles down it.

Losses from Poplar Ditch by seepage and evaporation.

No.	Date.	Discharge.	Distance.	Loss.
	1901.	*Cu. ft. per sec.*	*Miles.*	*Per cent.*
1	June 12	35.3	4.00	25
2	June 14	73.3	4.00	13
3	.....do	73.3	7.75	22
4	June 27	42.8	4.00	38
5	June 29	26.9	2.75	18
6	.....do	21.9	3.00	23

PLANO DITCH.

The Plano Ditch, during the season of 1901, furnished water for 55 acres of oranges and lemons, 29.5 acres of deciduous fruits, 155.5 acres of alfalfa, bur clover and Bermuda grass, 110 acres of vegetables, and 100 acres of barley, which were watered prior to April 27. The citrus trees are above the ditch, and pumps are used to raise the water.

From an incomplete record of gauge heights kept from April 27 to November 8, it is estimated that 2,768.3 acre-feet entered the ditch during that time. Using this amount and excluding the barley, which was not watered during the period, the duty is as shown below:

Duty of water under Plano Ditch, April 27 to November 8, 1901.

Area irrigated	acres..	350.0
Water used, April 27 to November 8	acre-feet..	2,768.3
Depth of water used in irrigation	feet..	7.91
Rainfall, April 27 to November 8	foot..	.38
Total depth of water received by land	feet..	8.29

The entire amount of water was not applied to the land. Besides that lost by seepage and evaporation, immense quantities were allowed to run to waste at the end of the ditch.

The ditch divides into two branches 1⅝ miles from its head On July 1 there was a flow of 7.5 cubic feet per second one-fourth mile below the head, 2.5 cubic feet per second in the lower branch at the point of division, and 2.1 cubic feet per second in the upper branch

2½ miles below the first measurement. This indicates a loss of 40 per cent in 2½ miles. The lower branch, on the other hand, gained 0.1 cubic foot per second, the discharge 1½ miles below its head being 2.6 cubic feet per second. There are 85 acres of Chinese vegetable garden under the lower branch, the remainder of the irrigated area being under the upper branch.

PIONEER CANAL.

The Pioneer Canal, on the Tule River, is thoroughly well managed. It is the only canal along this stream from which the water is sold by unit of quantity, and until such sales are instituted we can hardly hope for economy. In 1898 nearly all the private laterals of the system were equipped with either 4-inch "pressure gates" or small weirs. The whole system is now patrolled by two zanjeros, who deliver water to their patrons according to their orders. The orders must be placed in the office of the company three full days before the date of delivery and must state plainly the amount of water to be run, the unit used being the miner's inch for twenty-four hours.

The charge per inch for twenty-four hours depends upon the scarcity of water. During 1901, it was 3 cents prior to May 5; 5 cents from May 5 to July 15; 10 cents from July 15 to November 4, and 3 cents after November 4. In 1900 there was an insufficient supply and the charge per inch was 25 cents from August 6 to October 22. Water is sold to shareholders only.

The eastern and higher part of the system is given up to citrus fruits, and the lower part to deciduous fruits and alfalfa. The soil of the citrus belt is largely adobe and red soil, while that under the lower reaches of the canal is sandy loam. As in other districts where citrus fruits are raised, the orchards are almost without exception small, 10 acres being the average size.

In starting this investigation it was hoped to learn something about the duty of water under the whole canal, on the citrus groves, and on the deciduous orchards and alfalfa patches. Accordingly, three measuring flumes were constructed and a register used with each (Pl. XXVII, figs. 1 and 2). One was placed in the best available stretch, three-fourths of a mile below the head gate; a second on a lateral controlling 70 acres of oranges and lemons, and the third on a lateral under which there are 102 acres of deciduous fruit and alfalfa. In the latter part of the season a rank growth of Johnson grass in the citrus lateral, despite its constant removal, so retarded the flow through the flume that the ratings made earlier could not be used and the record is not given here. In its place a table based upon a set of the best measurements by the company is given.

Water is allowed to run through the Pioneer Canal for the entire year. Measurements were inaugurated in the flume near the head on

May 19, and the flow from that date until irrigation ceased on November 8 is given in the following table:

Discharge of Pioneer Canal near head, May 19 to November 8, 1901.

Day.	May.	June.	July.	August.	September.	October.	November.
	Acre-feet.	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*
1	....	60.28	101.69	43.42	41.10	53.90	54.79
2	....	59.86	104.77	42.00	43.10	53.66	59.55
3	....	61.28	106.79	46.99	41.90	54.87	63.24
4	....	65.57	107.44	48.51	39.57	54.47	62.55
5	....	65.92	105.49	40.44	37.48	54.55	59.69
6	....	62.98	101.69	34.90	37.47	51.85	58.36
7	....	62.38	96.67	35.65	39.54	50.08	57.71
8	....	55.96	100.73	41.15	37.82	48.39	57.71
9	....	56.67	93.44	35.34	36.52	47.03	....
10	....	49.40	88.55	34.79	35.64	46.50	....
11	....	48.46	84.61	33.40	33.64	46.50	....
12	....	46.14	75.33	32.32	29.97	45.62	....
13	....	52.38	78.78	31.52	30.91	45.68	....
14	....	61.27	79.44	33.45	31.24	45.23	....
15	....	81.26	79.44	37.81	31.30	45.23	....
16	....	96.04	79.44	39.53	34.37	46.34	....
17	....	96.04	80.19	36.40	19.06	46.06	....
18	....	96.04	77.85	39.86	33.71	45.82	....
19	65.84	96.04	72.86	42.04	33.64	47.48	....
20	61.38	96.04	73.68	40.50	34.89	48.84	....
21	62.49	93.69	72.41	39.48	34.96	49.15	....
22	55.53	107.67	67.77	40.88	34.83	46.51	....
23	52.52	107.45	69.55	41.54	39.38	45.81	....
24	50.06	102.64	72.34	43.02	49.84	50.61	....
25	62.02	105.18	68.74	38.92	51.06	52.56	....
26	60.97	105.72	67.84	37.01	50.22	64.64	....
27	53.01	100.42	66.10	36.40	48.54	86.07	....
28	63.58	98.54	63.16	35.26	49.15	74.44	....
29	61.46	101.37	60.92	34.78	48.31	58.77	....
30	59.03	101.69	50.00	36.66	50.60	56.74	....
31	60.94	....	44.28	40.19	....	55.28	....
Total	768.83	2,394.38	2,491.99	1,194.16	1,159.76	1,618.68	473.60

A copy of the company's record of water used during the entire year has been obtained, and the daily flow, expressed in acre-feet, is given below. No water was used in February. The irrigation season was supposed to have ended with the first days of November, but a protracted dry spell caused some of the orchardists to again use water at the end of December.

Company's record of water used under Pioneer Canal, 1901.

Day.	January.	March.	April.	May.	June.
	Acre-feet.	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*
1	....	1.00	10.60	6.08	3.00
2	....	1.00	11.00	4.28	1.92
3	6.00	1.00	14.40	4.00	2.92
4	8.00	....	30.28	3.20	.84
5	8.00	....	31.28	3.36	4.72
6	8.00	....	29.40	2.84	5.56
7	8.00	....	20.40	2.80	5.88
8	8.00	....	28.40	2.24	5.20
9	4.00	....	27.60	8.12	9.72
10	3.00	....	38.56	10.12	7.00
11	8.00	....	19.96	7.20	5.00
12	8.00	....	31.48	1.32	8.16
13	2.00	....	31.20	2.00	16.60
14	....	....	28.20	2.52	23.68
15	....	....	28.00	3.52	29.00
16	....	....	32.20	7.40	26.84
17	....	....	24.40	8.68	28.52
18	....	....	28.44	8.16	27.08
19	7.00	....	39.40	5.24	28.04
20	7.00	....	32.72	2.48	29.12

Company's record of water used under Pioneer Canal, 1901—Continued.

Day.	January.	March.	April.	May.	June.
	Acre-feet.	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*
21	7.00	....	25.44	10.52	40.28
22	7.00	....	23.24	10.92	31.84
23	7.00	....	29.48	11.80	33.24
24	1.76	....	11.04	18.04	38.24
25	....	....	.12	14.80	33.08
26	4.00	18.20	....	.20	33.88
27	2.00	16.00	5.04	.20	33.64
28	....	16.60	17.40	1.12	39.40
29	....	14.60	30.44	.92	48.76
30	11.40	22.60	23.48	5.32	40.68
31	....	15.20	....	5.32	....
Total	125.16	191.20	708.60	174.72	656.84

Day.	July.	August.	September.	October.	November.	December.
	Acre-feet.	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*
1	38.28	15.00	17.72	8.48	6.00	....
2	35.48	17.06	17.84	5.28	7.80	....
3	42.76	14.36	17.92	8.16	12.00	....
4	53.72	16.32	26.24	9.04	12.00	....
5	47.12	13.96	20.64	11.08	12.00	....
6	50.04	16.04	18.56	10.12	8.00	0.80
7	37.12	16.32	15.60	10.92	6.00	....
8	39.44	19.32	16.12	4.96	6.00	....
9	40.24	18.76	13.88	4.04	3.00	....
10	35.80	13.36	16.56	6.08	3.00	.48
11	41.28	11.56	15.42	7.80	3.00	....
12	35.80	13.20	15.72	6.60	....	.32
13	31.68	11.52	14.04	8.04	....	1.36
14	29.60	12.36	14.96	6.56	....	1.12
15	31.88	12.60	12.00	11.52	....	1.12
16	23.12	16.52	6.60	10.56	....	2.92
17	19.16	16.12	8.92	13.80	....	2.12
18	17.16	10.32	7.52	15.84	....	4.60
19	20.68	13.96	6.92	16.08	....	6.16
20	21.28	17.20	12.36	16.96	....	8.72
21	22.56	15.72	10.84	13.56	....	6.88
22	21.80	18.64	9.84	9.24	....	10.08
23	17.40	17.00	7.76	14.00	.16	12.12
24	10.76	16.52	9.92	8.68	.16	13.64
25	21.72	17.04	10.92	11.56	....	6.76
26	15.44	14.68	11.08	8.44	....	8.08
27	12.96	13.52	13.64	10.12	....	13.68
28	8.12	14.24	9.60	8.40	....	13.08
29	10.92	16.08	11.92	3.64	....	14.48
30	13.80	16.20	6.80	7.16	....	11.28
31	14.56	18.56	....	6.96	....	13.92
Total	861.68	474.08	397.86	293.68	79.12	158.72

The monthly totals of the above table are grouped below for easier comparison. The first shows the amount that entered the ditch, the second that actually delivered to the irrigator, and the third the percentage of the discharge at the head which was delivered to consumers.

Percentage of water diverted by Pioneer Canal delivered to consumers.

Month.	Discharge of flume at head.	Water delivered to consumer.	Percentage of flow delivered.
	Acre-feet.	*Acre-feet.*	*Per cent.*
May 19 to 31	769	87	11
June	2,394	657	27
July	2,492	862	35
August	1,194	474	40
September	1,160	398	34
October	1,619	294	18
November	474	70	15
Total	10,102	2,842	28

The amount used, as shown by the company's record, was but 28 per cent of the amount entering the ditch for the entire time of record, and only about 36 per cent for the months of July, August, and September, when we should expect deliberate waste to be a minimum. The measuring flume was rated by current-meter measurements taken during May and June. In anticipation of the effect of weed growth during the latter part of the season, the lower values for late June were given greater weight than the larger values for May, the result being an average curve for the entire season, too small for the earlier part and too large for the later period. The growth of aquatic weeds in shallow ditches with a small velocity and under a torrid sun is so rapid that the capacity of the ditch is often reduced 30 per cent (Pl. XXVIII, fig. 1). That a marked reduction in the flow took place on the Pioneer Canal, even though the weeds were from time to time removed, is evident from the seepage measurements during July and August.

The acreage and value of the crops irrigated during 1901 are as follows:

Acreage and value of crops irrigated under Pioneer Canal, 1901.

Crop.	Acres.	Value.	Value per acre.
Oranges	669	$91,768	$137.17
Lemons	138	7,205	52.21
Deciduous fruits	204	7,371	36.13
Alfalfa	218	4,059	18.62
Vegetables	32	655	20.47
Total	1,261	111,058	88.07

The duty of water, using both the yearly record of the company and the amount flowing through the measuring flume from May 19 to November 8, is summarized as follows:

Duty of water under Pioneer Canal, 1901.

Items.	Company's record, Jan. 1 to Dec. 31.	Flume measurement, May 19 to Nov. 8.
Area irrigated ... acres	1,261	1,261
Water used ... acre-feet	4,021.66	10,101.4
Depth of water used in irrigation ... feet	3.19	8.01
Rainfall ... foot	.84	.22
Total depth of water received by land ... feet	4.03	8.23

When it is remembered that the company's record is for the amount delivered at the field itself, the depth of irrigation, as shown above, seems excessive. Many of the citrus groves are on the lower hill slopes, and it is quite common to find large pools at the lower levels of the orchards and on roadways beyond during the irrigation period

FIG. 1.—PIONEER DITCH, SHOWING WEEDS IN THE CANAL.

FIG. 2.—WASTEFUL SIDEHILL IRRIGATION.

(Pl. XXVIII, fig. 2). Side-hill watering necessitates great care, and where this is not exercised a high duty can not be expected.

Measurements taken to determine the loss due to seepage and evaporation show a comparatively small loss between the head and the irrigated lands. The measurements made are as follows:

Seepage measurements on Pioneer Canal, 1901.

Date.	Discharge.	Length of section.	Loss.
1891.	*Cubic feet per second.*	*Miles.*	*Per cent.*
May 20	45	2.8	6
May 31	37.7	2.8	1.3
Do	27.7	4.8	7
July 10	37.2	5	11
Do	23.9	5.5	6

With the exception of the last, all the measurements were taken in or near the measuring flume, three-fourths mile below the head gate. The small losses shown by the measurements of May 31 may be attributed to the fact that the banks had been well saturated by a rainfall of 1.73 inches on May 25 and 26. The great loss occurs below the first 5 miles. Owing to the numerous diversions, satisfactory measurements of the waste could not be made on the lower sections of the canal, but the loss in one of the laterals may be cited as an illustration. On July 10 a measurement at the head of one of the better laterals gave 0.44 cubic foot per second, while there was but 0.16 cubic foot per second three-fourths of a mile below, a loss of 64 per cent. It must be borne in mind that a large part of the water entering the canal was allowed to pass through unused. The flume record simply shows the amount that might have been used.

The past season, 1901, was the only year of plenty in the last five. In order to be secure against lack of water, the Pioneer Canal Company started two centrifugal pumps, one 10-inch and one 6-inch, in 1897. When the ditch supply became low it was replenished by the pumps. The past season was the first since the pumps were put in in which there was no need of pumping. Besides the company's pumping plant there are a number of private pumps. None had to be used in 1901.

DUTY OF WATER ON CITRUS GROVES.

In order to make a more direct study of the duty of water used on the citrus groves, twenty-one orchards were chosen on which it was thought the company's measurements were especially good. In the following table are recorded the soil, the acreage, the amount of water used monthly, the total amount used, the depth of irrigation, the total crop value, and the return per acre-foot used:

Acreage and value of crops, and water delivered, for selected orchards under Pioneer Canal, 1901.

Name.	Soil.	Acreage of crops.				Water delivered.								Depth of irrigation.	Total value of crops.	Return per acre-foot used.
		Oranges.	Lemons.	Deciduous.	Total.	April.	May.	June.	July.	August.	September.	October.	Total.			
						Acre-feet.	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*	*Feet.*		
M. Davidson	Adobe	20	2		22	0.60		8.96	2.72	9.04	11.56		32.88	1.49	$3,500	$106.44
R. C. Kling	do	5	1		6	.80		10.60	8.60		3.40	3.36	26.76	4.46	1,500	56.05
A. A. Abbey	do	6			6			3.60	4.80	8.00	4.20	1.80	22.40	3.73	1,750	78.13
E. O. Giddings	do	9	4		13		4.12		1.60	2.64	2.60	.64	11.60	.89	350	30.17
Mary Hathaway	do	10			10			7.80		9.44	1.44	7.80	26.48	2.65	3,500	132.18
Frank Putnam	do		4		4				3.00		3.00		6.00	1.50	40	6.67
W. W. Henry	do	20			20			7.80	8.20	7.80	5.60	2.56	[a] 42.96	2.15	6,000	139.66
F. E. Woodley	do	8		[b] 2	10			3.04	4.60	4.00	2.40		14.04	1.40	836	59.54
E. Newman	do	4	3	2	9			6.60	12.60		8.32		27.52	3.06	1,000	36.34
W. J. McCown	Red soil and adobe.	7			7	.80	1.00	4.80		3.84	3.84	1.92	[c] 16.60	2.37	460	27.71
Chas. Kern	Red soil	10			10		3.20		5.60	5.60	4.20		18.60	1.86	800	43.01
M. A. Burgess	Adobe	25			25		3.00	3.12	8.88	4.40	10.84	2.86	32.10	1.28	3,500	109.03
Brey & Lackey	do	12			12			7.00		4.00	4.12		15.12	1.26	3,000	198.41
J. Weisenberger	Red soil	20			20			18.16	8.40	22.92			49.48	2.47	2,250	45.47
Thos. Feemster	Adobe	10			10			5.64		7.04		3.12	15.80	1.58	1,000	63.29
Lena M. Eaton	do	5			5			4.00	4.64	3.64	2.80	2.24	17.32	3.46	1,200	69.28
R. H. T. Marriner	do	4		6	10		1.76		5.28	2.24	1.84	2.40	13.52	1.35	275	20.34
Brumfield & Hardman	do	12	7		19				11.56	12.48	2.80	1.44	28.28	1.49	2,236	79.07
Mrs. W. H. Norris	do	5			5		.20	.60	12.88	5.08	.44		19.20	3.84	731	38.07
A. G. Schulz	do	12			12			12.80	2.60	12.00	9.68	2.40	39.48	3.29	2,600	65.86
Jos. Willson	do	12			12			4.80	3.24	6.12	3.60		17.76	1.48	2,470	139.08
Total		216	21	10	247	2.20	13.28	109.32	109.20	130.28	86.18	32.04	493.90	2.00	38,998	78.96

[a] Includes 11 acre-feet used in January.

[b] Alfalfa.

[c] Includes 0.4 acre-foot used in November.

Fig. 1.

Fig. 2.

FURROW IRRIGATION, PIONEER DITCH.

The furrow system is the one universally used in the irrigation of the citrus groves in this locality. (Pl. XXIX.) The common practice is to run three or four furrows between rows of trees. Where the trees are young, the furrows next to the trees are often the only ones used, or, if the full number is used, the space between the trees is not so thoroughly wetted as is the practice where trees are in full bearing. This explains the high duty of the water used on the orchard of Mr. Giddings, where the trees are all young and bearing for the first time, as evidenced by the crop value. The average depth of irrigation for the entire group is only 63 per cent of that for the entire system, and the average return per acre-foot used, $78.96, is almost three times that for the system, $27.61.

DUTY OF WATER ON DECIDUOUS FRUITS AND ALFALFA.

The record of the flow through the flume constructed on the lateral in the deciduous fruit and alfalfa district (which we shall designate as flume lateral No. 2) was started on May 21, 1901. Water was first used on the land under the flume on March 27, and the company's measurements from that date to the establishment of the measuring station have been obtained. The amounts and dates of use are shown in the following table:

Water used under flume lateral No. 2, 1901.

Day.	March.	April.	May.	June.	July.	August.
	Acre-feet.	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*
1					3.79	1.60
2					2.31	2.00
3					1.97	2.00
4		1.80			2.46	
5		2.00			3.18	
6		1.20			2.76	
7						
8						
9						
10		3.20				
11						
12				0.60		
13						
14				1.60		
15						
16					0.20	
17					.20	
18		1.04				
19		5.60				
20		2.20		5.61	1.64	
21			3.88	5.61	.60	
22		1.20	3.73	5.45		
23		1.20	3.98	6.42	.80	
24			3.13	6.72		
25				6.50	1.00	
26				5.65		
27	2.40			4.66		
28	2.60			5.49		
29	2.80	1.64		5.85		
30	2.80	1.60		5.33		
31	2.40				1.23	
Total	13.00	22.68	14.72	65.49	22.14	5.60

The water was used by 10 irrigators. The surface has but little slope, and one-fifth of the soil is adobe, the remainder being sandy loam. The acreage and value of the crops irrigated in 1901 are as follows:

Acreage and value of crops irrigated under flume lateral No. 2, 1901.

Crop.	Acres.	Total value.	Value per acre.
Oranges	1	$125	$125.00
Deciduous fruits	57	2,540	44.56
Alfalfa	37	731	19.76
Vegetables	7	105	15.00
Total	102	3,501	34.32

Duty of water under flume lateral No. 2, 1901.

Area irrigated	acres..	102.00
Water used	acre-feet..	143.63
Depth of water used in irrigation	feet..	1.41
Rainfall, March–August, 1901	foot..	.37
Total depth of water received by land	feet..	1.78

The higher duty of water is to be expected, even though the nature of the soil would suggest otherwise. Very little was used after the first week in July, while the irrigation of the citrus groves was carried into November. The return per acre-foot used was $24.34, 12 per cent less than that for the whole ditch.

PLEASANT VALLEY DITCH.

The Pleasant Valley Ditch diverts water from the west side of the main river about 15 miles above Porterville. The ditch was not used this season until April 21, and a record of the flow for the entire irrigation season was obtained. The gauge rod was placed in one of the company's flumes near the head. The amount of water entering the ditch from the beginning of the season to October 11, when irrigation ceased, follows:

Discharge of Pleasant Valley Ditch, 1901.

Day.	April.	May.	June.	July.	August.	September.	October.
	Acre-feet.	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*
1		0.67		17.80	17.80	7.98	10.06
2		.67		17.80	17.80	7.06	10.06
3		.67		16.38	16.38	7.98	10.06
4		.67		17.80	20.89	7.98	10.06
5		.67		10.06	24.22	7.06	9.02
6		.67		17.80	24.22	7.98	10.06
7		.67	7.98	17.80	17.80	7.98	10.06
8		.67	7.98	17.80	24.22	10.06	9.02
9		.67	7.98	17.80	22.55	10.06	10.06
10		.67	10.06	14.97	24.22	10.06	7.30
11		.67	10.06	14.97	24.22	12.40	7.98
12		.67	10.06	10.06	6.14	11.23	
13		2.12	10.06	17.80	6.14	12.40	
14		2.12	10.06	14.97	5.34	10.06	
15		2.12	10.06	14.97	6.14	10.06	
16		2.12	10.06	10.06	5.34	11.23	
17		3.21	10.06	10.06	7.98	12.40	
18		3.21	10.06	7.98	7.98	12.40	

PLEASANT VALLEY FROM SPROTT ORCHARD.

Discharge of Pleasant Valley Ditch, 1901—Continued.

Day.	April.	May.	June.	July.	August.	September.	October.
	Acre-feet.	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*
19	....	3.21	10.06	7.98	7.06	12.40	....
20	....	6.14	10.06	7.98	7.06	11.23	....
21	3.21	6.14	10.06	7.98	7.98	12.40	....
22	3.21	6.14	10.06	7.98	7.98	12.40	....
23	3.21	6.14	10.06	4.55	7.98	10.06	....
24	3.21	10.06	10.06	4.55	9.02	7.98	....
25	3.21	10.06	14.97	3.21	7.98	7.98	....
26	4.55	10.06	14.97	3.21	7.06	10.06	....
27	4.55	10.06	14.97	2.12	7.06	9.02	....
28	4.55	10.06	12.40	2.12	7.98	9.02	....
29	4.55	10.06	12.40	2.12	7.98	7.98	....
30	4.55	....	17.80	16.38	9.02	9.02	....
31	....	....	....	17.80	10.06	....	....
Total	38.80	111.07	262.35	354.86	383.60	295.93	103.74

The acreage, amount, and value of the crops irrigated in 1901 are shown in the following table:

Acreage irrigated and crop yields and values under Pleasant Valley Ditch, 1901.

Crop.	Acres.	Total yield.	Yield per acre.	Total value.	Value per acre.
Oranges	156.25	5,075 boxes	32.5 boxes	$9,697.75	$62.07
Lemons	31.00	1,870 boxes	60.3 boxes	2,215.00	71.45
Apples	6.00	6.5 tons	1.1 tons	150.00	25.00
Alfalfa	16.00	37 tons	2.3 tons	133.00	8.31
Beans and corn	13.00	....	....	264.50	20.35
Garden truck	23.50	....	....	795.00	33.83
Total	245.75	....	....	13,255.25	53.94

Duty of water under Pleasant Valley Ditch, 1901.

Area irrigated	acres..	245.75
Water used	acre-feet..	1,550.35
Depth of water used in irrigation	feet..	6.31
Rainfall, April 21 to October 11	foot..	.35
Total depth of water received by land	feet..	6.66

From the estimated depth of irrigation, it is evident that only a portion of the water reached the irrigated fields. Two sets of measurements taken on the lower half of the ditch show the loss by seepage and evaporation to be very great. On July 2 a flow of 5.6 cubic feet per second was recorded 4½ miles above the Sprott orchard (XXX), while at the orchard there was but 1.8 cubic feet per second, 1 cubic foot per second being diverted between the two points. This means a loss of 50 per cent in 4½ miles. On August 1 the flow was 4.9 cubic feet per second 5 miles above the Sprott orchard and only 2.8 cubic feet per second at the orchard, no water being used at intermediate points. This is a loss of 43 per cent in 5 miles.

The president of the ditch company, Mr. W. E. Sprott, was sufficiently interested in the investigation to construct a flume for the measurement of the water used on his place. Gauge readings were taken several times each day during the irrigation period, and from these the amount used has been derived.

Water used on Sprott orchard, 1901.

Day.	July.	August.	September.	October.
	Acre-feet.	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*
1		2.61		
2		3.64	0.56	2.17
3	1.04	5.04	2.24	3.45
4		1.98	3.17	4.02
5	2.56		3.41	4.52
6	3.47		3.79	1.45
7	2.54		3.18	
8	.87		1.08	
Total	10.48	15.27	17.43	15.61

Half of the trees in this orchard were planted in 1895, and half in 1896. Most of them were set on a sidehill, and the utmost care has to be exercised in irrigating to prevent erosion. The acreage, yield, and value of the crop are as follows:

Acreage, yield, and value of crop of Sprott orchard, 1901.

Crop.	Acres.	Total yield.	Yield per acre.	Total value.	Value per acre.
		Boxes.	*Boxes.*		
Oranges	28	1,500	53.6	$3,000	$107.14
Lemons	10	800	80.0	750	75.00
Total	38			3,750	98.68

Duty of water on Sprott orchard, 1901.

Area irrigated	acres..	38.00
Water used	acre-feet..	58.79
Depth of water used in irrigation	feet..	1.55
Rainfall, July to October	foot..	.07
Total depth of water received by land	feet..	1.62

Aside from the factors of personal skill and carefulness, there is no reason why less water should be used on the Sprott orchard than on an equal area elsewhere under the ditch. Excepting about 25 acres of very sandy soil, the soil of the orchard is adobe, the prevailing soil under the ditch. Owing to the great slope, a very small stream must be used in the furrows, and evaporation is thus increased. This is true for most of the citrus groves in the vicinity, and a lower duty must be expected here than where the surface is comparatively level. The return for each acre-foot of water used on the Sprott orchard was $63.79, while that for the whole ditch was only $8.55.

DIVERSIONS FROM SOUTH FORK.

SMALL DITCHES.

The only diversion of importance from the South Fork is the South Tule Independent Ditch. There are a few very small ditches within the Tule River Indian Reservation, used for irrigating the trees and

grain of the Indians. Besides these, there is the King Ditch, which heads on the west side of the South Fork, one-half mile below the South Tule Independent Ditch. The King Ditch was constructed in 1873 and is slightly over one-half mile in length. The irrigated acreage in 1901 included 4 acres of alfalfa, 8½ acres of trees, and 12 acres of grain. The full capacity of the ditch was found to be 1.9 cubic feet per second by a measurement made May 30, 1901.

SOUTH TULE INDEPENDENT DITCH.

The South Tule Independent Ditch takes water from the east side of the South Fork. It was first constructed in 1872 and remodeled in 1896. It has a length of 10 miles. For the first 4½ miles it has a width of 5 feet and a grade of 8 feet to the mile, and for the remainder of its course the width is 6 feet and its grade 6 feet to the mile. The cost of reconstruction in 1896 was $3,083. The ditch is owned by a corporation of farmers, with 480 shares at $50 per share. During the irrigation season a ditch tender is employed at $1.75 per day to apportion the water according to the shares of stock. There was a bountiful supply during 1901 and each irrigator took what he wished.

The ditch was not put into use in 1901 until May 8. The ditch tender made daily readings on a rod placed in a straight section one-half mile below the head. The results of the measurements are as follows:

Discharge of South Tule Independent Ditch, 1901.

Day.	May.	June.	July.	August.	September.	October.
	Acre-feet.	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*
1		9.46	20.04	10.76	8.84	8.84
2		9.46	20.04	10.76	8.84	8.84
3		9.46	20.04	10.76	8.84	8.84
4		9.46	20.04	10.76	8.84	8.84
5		9.46	20.04	10.76	8.84	8.84
6		9.46	20.04	10.76	8.84	8.84
7		9.46	20.04	10.76	8.84	8.84
8	7.35	9.46	20.04	10.76	8.84	8.84
9	7.35	9.46	20.04	10.76	8.84	10.76
10	9.46	9.46	20.04	10.76	8.84	10.76
11	9.46	9.46	20.04	10.76	8.84	10.76
12	9.46	9.46	20.04	10.76	8.84	10.76
13	9.46	9.46	20.04	10.76	7.10	10.76
14	9.46	9.46	20.04	10.76	7.10	10.76
15	9.46	9.46	20.04	10.76	7.10	10.76
16	9.46	9.46	20.04	10.76	7.10	10.76
17	9.46	14.34	20.04	10.76	7.10	8.84
18	9.46	14.34	20.04	10.76	7.10	8.84
19	9.46	14.34	20.04	10.76	7.10	8.84
20	7.35	14.34	20.04	10.76	7.10	8.84
21	7.35	14.34	17.07	8.84	8.84	8.84
22	7.35	14.34	17.07	8.84	8.84	8.84
23	7.35	14.34	17.07	8.84	8.84	7.10
24	7.35	14.34	17.07	8.84	10.76	7.10
25	7.35	14.34	17.07	8.84	10.76	7.10
26	7.35	14.34	17.07	8.84	10.76	7.10
27	7.35	14.34	17.07	8.84	10.76	7.10
28	7.35	14.34	17.07	8.84	10.76	7.10
29	7.35	14.34	17.07	8.84	10.76	5.51
30	7.35	14.34	17.07	8.84	10.76	5.51
31	7.35		17.07	8.84		5.51
Total	197.50	352.12	588.57	312.44	264.72	268.97

The average amount and value of crops irrigated during 1901 are given below. In calculating the yield and value per acre for the oranges, only 111.6 of the 126.93 acres were used, as 15.33 acres are in young nonbearing trees. In estimating the value of the nursery stock crop, it was the common practice to consider that the stock had doubled in value since the beginning of the season; hence the very large value per acre.

Acreage, yield, and value of crops irrigated under South Tulè Independent Ditch, 1901.

Crop.	Acres.	Total yield.	Yield per acre.	Total value.	Value per acre.
Oranges	[a] 126.93	8,008 boxes	71.8 boxes	$12,405.00	$111.15
Lemons	32.35	1,570 boxes	48.5 boxes	1,570.00	48.53
Deciduous fruit	14.85			445.00	29.97
Alfalfa	47.50	131 tons	2.8 tons	648.00	13.64
Corn	27.00	18.5 tons	0.7 ton	462.50	17.13
Garden truck	9.38			475.00	50.64
Nursery stock	5.22			4,787.50	917.14
Melons	2.75			285.00	103.64
Total	265.98			21,078.00	84.09

[a] 15.33 acres of young trees.

Duty of water under South Tule Independent Ditch, 1901.

Area irrigated	acres..	265.98
Water used	acre-feet..	1,984.32
Depth of water used in irrigation	feet..	7.46
Rainfall, May 8 to October 31	foot..	.22
Total depth of water received by land	feet..	7.68

The South Tule Valley is almost directly across the Tule River from Pleasant Valley. The soil is adobe and red land, and all other conditions seem to be the same in the two valleys. The duty of water should be as high under the South Tule Independent Ditch as on the Sprott orchard. Besides the natural losses due to seepage and evaporation, there is great misuse of water. In many places it is allowed to tear down precipitous laterals and waste as it will.

Two sets of measurements were made, at the head and at a point 5 miles below the head, to determine the loss due to evaporation and seepage. July 3 the discharge at the head was 7.9 cubic feet per second, and 5 miles below the head 6.8 cubic feet per second, a loss of 14 per cent. August 4 the discharges at the head and 5 miles below were 5.6 and 4.9 cubic feet per second, respectively, a loss of 12½ per cent.

The loss in the last 5 miles of the ditch is greater than in the first half, but no practical measurements could be made as small streams of water were diverted in many places for stock and other purposes. A great amount, however, simply runs to waste, and a high duty will not be shown on the ditch until the scarcity of water impels economy. The return per acre-foot entering the ditch was $10.63.

As both the Pleasant Valley and the South Tule Valley are much higher than Porterville their rainfall is probably much heavier, but as no record had been kept in either valley that for Porterville had to be used.

PUMP IRRIGATION AT LINDSAY.

The citrus groves about Lindsay, 10 miles northwest of Porterville, are interesting in that they rely entirely upon wells for their irrigation supply. There are now at least 25 pumping plants in use, and, excepting one steam engine, all receive their power from the Mount Whitney Electric Company. The majority of the pumps are centrifugal. They are placed in pits varying in depth below the surface from 19 to 47 feet, the water during pumping standing 8 to 30 feet below the pumps. In the immediate vicinity of Lindsay water is elevated from 40 to 70 feet. On the higher land, just east of the town, Whitmore Brothers use a No. 2 Fulton double-acting pump to raise water from 140 feet below the surface and force it 61½ feet more, a total elevation of 201½ feet.

Most of the smaller plants pump constantly throughout the irrigation season, which generally begins in May and ends in November. In a number of places the water is allowed to run in open ditches, in one instance for a distance of 1¼ miles. The owners realize the loss this necessitates, and pipes and flumes will soon be in general use. The water is applied by running it through three or four furrows between rows of trees. The soil is loam and sandy loam.

As the pumping rate of most of the private plants is very variable, the results obtained by the Lindsay Water Development Company only will be used in estimating the duty of the water pumped. This company uses a 6-inch centrifugal pump, with a working capacity of 50,000 gallons per hour. The depth to surface water is about 35 feet in winter and 45 feet in summer, and drops to 71 feet during pumping. The total elevation of water, including pipe friction, is 94 feet. A 50-horsepower motor is used, at a yearly cost of $50 per horsepower.

Water is sold by the "unit," a unit being a six hours' flow of 50,000 gallons per hour, equal to 1.089 acre-feet. During 1901 the price per "unit" was reduced from $7.40 to $6, and the manager of the company thinks that the rate will not be more than $5 during the next season.

The following table shows the acreage, amount of water received, and the depth of irrigation for the four past seasons. By an inspection of the table it will be seen that the depth of irrigation is in a few cases as low as 0.65 foot, and is not often above 2 feet. The averages for the four years as shown are 1.00, 1.63, 1.50, and 1.14.

Duty of water pumped by the Lindsay Water Development Company.

Irrigator.	1898.			1899.			1900.			1901.		
	Area.	Water delivered.		Area.	Water delivered.		Area.	Water delivered.		Area.	Water delivered.	
		Quantity.	Depth.		Quantity.	Depth.		Quantity.	Depth.		Quantity.	Depth.
	Acres.	*Acre-feet.*	*Feet.*	*Acres.*	*Acre-feet.*	*Feet.*	*Acres.*	*Acre-feet.*	*Feet.*	*Acres.*	*Acre-feet.*	*Feet.*
M. R. Beerson	10.00	8.71	0.87	10.00	16.84	1.63	10.00	15.25	1.52	11.00	13.07	1.19
R. E. W. Besant	26.45	51.18	1.93	26.45	51.18	1.93						
H. S. Black	29.68	26.14	.88	29.68	74.05	2.50	29.68	54.45	1.83	33.00	21.78	.66
C. J. & W. R. Carle	24.00	32.67	1.36	24.00	19.60	.82						
H. M. Cowper	42.13	41.38	.98	42.13	100.19	2.38	20.36	39.20	1.93	20.00	28.31	1.42
W. N. Cowper	16.82	9.80	.58	16.82	34.85	2.07	16.82	29.40	1.75	17.00	18.51	1.09
M. E. Chapin	13.44	8.71	.65	13.44	15.25	1.13	23.44	15.25	.65	10.00	9.80	.98
J. B. Eager	20.00	16.34	.82	20.00	37.03	1.85	20.00	44.10	2.21			
B. V. Hardman	17.00	20.69	1.22	17.00	43.56	2.56	17.00	30.49	1.79			
M. E. Irwin	20.00	15.25	.76	20.00	19.60	.98	20.00	41.38	2.07	20.00	30.49	1.52
J. E. Johnson	68.00	68.61	1.01	68.00	66.43	.98						
W. Drake	20.00	17.42	.87	20.00	39.20	1.96						
S. A. Allen	10.00	8.71	.87	10.00	16.34	1.63	10.00	15.25	1.53	10.00	10.89	1.09
J. M. Palton	10.00	9.80	.98	10.00	19.60	1.96	10.00	18.51	1.85	10.00	13.07	1.31
Wm. Ramsay	30.00	22.87	.76	30.00	51.18	1.71	30.00	29.40	.98			
W. C. Palton	10.00	8.71	.87	10.00	14.16	1.42	10.00	17.42	1.74	11.00	10.89	.99
Lindsay Orchard Co	74.59	81.68	1.10	68.00	102.37	1.51	30.00	30.49	1.02	20.00	26.14	1.31
M. E. Seybolt	20.00	15.24	.76	20.00	30.49	1.52						
Puro Bros	22.54	22.87	1.01	22.54	38.12	1.69						
Curtis & Co	16.00	15.25	.95	16.00	19.60	1.23						
J. Curtis	10.00	8.71	.87	10.00	10.89	1.09	15.62	20.69	1.32	16.00	14.16	.89
Mrs. C. Butler							6.00	10.89	1.82	6.00	7.62	1.27
L. Wolf							10.00	6.53	.65	6.00	6.53	1.09
B. Prior										17.00	31.58	1.86
R. C. Johnson										60.00	62.07	1.03
Total	510.65	510.74	1.00	504.06	820.03	1.63	278.92	418.70	1.50	267.00	304.91	1.14

IMPROVEMENT OF DITCHES.

Every ditch described in this report is properly situated for the irrigation of at least twice the area served in 1901. Owing to frost zones, the Pioneer and Plano ditches would command more citrus fruit land if placed on higher ground. This change could be well made in the case of the Pioneer only, and a survey would be necessary to determine the cost. Land values in the Tule River Basin are necessarily dependent on the use to which the land is put. Grain land varies from $6 to $20 per acre, while alfalfa land under the ditches runs from $40 to $75. Land under a ditch which could be used for citrus culture is worth at least $100 per acre, and a four-year-old grove at least $500 per acre. Only the higher land close to the foothills can be used for oranges and lemons, but nearly the entire area under the ditches described could be used for alfalfa and deciduous fruit.

As one drives westward from Porterville he can but contrast the neglected condition of deciduous orchards and vineyards under the lower ditches with the highly cultivated citrus groves he has left behind. The reason is held to be lack of market rather than scarcity of water or want of energy. The general experience has been that after the high railroad rates and higher commissions have been paid, the orchardist has little or nothing for his time and labor. Accordingly a great many orchards and vineyards have been abandoned, though some few well-kept ones still exist, especially under the Fine Ditch. Within the past two years two creameries have started operations west of Porterville, and most of the farmers see their salvation in the raising of alfalfa for dairy stock. This will certainly lead to improved methods as the demand for alfalfa increases. After this is done the effectiveness of the system must be increased by lessening seepage.

The following table brings together the measurement of losses from seepage and evaporation given in the preceding pages:

Losses from canals and ditches on Tule River by seepage and evaporation.

Name of canal ditch.	Flow at head.	Distance between measurements.	Loss.
	Cu. ft. per sec.	*Miles.*	*Per cent.*
Callison Slough, June 6, 1901	55	2.5	13
Tipton Irrigation District:			
May 28, 1901	75.5	10	68
June 17, 1901	48.7	12	81
Fine Ditch:			
May 24, 1901	21.2	1.5	17
June 18, 1901	31.9	1.5	24
Vandalia Ditch:			
June 18, 1901	16	2	92
June 21, 1901	16	2	89
July 1, 1901	10.2	1.5	96
Porter Slough:			
June 1, 1901	97.6	2	1.6
July 9, 1901	3.7	4	46

Losses from canals and ditches on Tule River by seepage and evaporation—Continued.

Name of canal ditch.	Flow at head.	Distance between measurements.	Loss.
	Cu. ft. per sec.	*Miles.*	*Per cent.*
Poplar Ditch:			
June 12, 1901	35.3	4	25
June 14, 1901	73.3	4	13
Do	73.3	7.75	22
June 27, 1901	42.8	4	38
June 29, 1901	26.9	2.75	18
Do	21.9	3	23
Plano Ditch, July 1, 1901	7.5	2.5	40
Pioneer Canal:			
May 20, 1901	45	2.8	6
May 31, 1901	37.7	2.8	1.3
Do	27.7	4.8	7
July 10, 1901	37.2	5	11
Do	23.9	5.5	6
Pleasant Valley Ditch:			
July 2, 1901	5.6	4.5	50
August 1, 1901	4.9	5	43
South Tule Independent Ditch:			
July 3, 1901	7.9	5	14
August 4, 1901	5.6	5	12.5

Beneath the sandy loam soil of this region is a substratum of clay. In many places this could be excavated at little expense. Simply throwing the pulverized clay into the ditch and causing it to be distributed by agitating the water would do much toward puddling the the banks and rendering them impervious.[a]

All citrus groves under the Pioneer, Pleasant Valley, and South Tule Independent ditches are young. With age they will become more valuable and irrigation water a richer prize. From the present enormous loss by seepage and evaporation it would seem that these ditches could soon afford to use cement lining. In southern California, where the groves are older and more numerous and water scarcer and hence more valuable, a number of ditches have been coated with a cement mortar. On the Gage Canal the contract price for regrading and plastering the sides and bottom of a section, having a bottom width of 7 feet, a depth of 4 feet, and side slopes of 1 to 1, was 75 cents per linear foot. The coating was three-fourths of an inch thick, and was composed of 1 part cement to 4 parts sand. On the North Riverside and Jurupa Canal a plaster coat of from one-eighth to one-fourth of an inch thick was used.

The average section of the Pleasant Valley and South Tule Independent ditches has a bottom width of 6 feet, a depth of 3 feet, and side slopes of 1 to 1. Allowing for the increased cost of material, these channels could probably be lined with a thin coat of cement mortar at the same price as the Gage Canal—about $4,000 per mile. The Pioneer Canal has an average bed width of 10 feet for the first 5 miles, and a width of 6 feet for the remainder of its course. A rough estimate on the lining of the first section would be $4,500 per mile.

[a] U. S. Dept. Agr., Office of Experiment Stations Bul. 86, p. 37.

The Pioneer Canal, being the lowest of the three referred to, is the most likely to experience a shortage. This was so in 1900. As cited above, the charge for water from August 6 to October 22, 1900, was 25 cents per inch for twenty-four hours. It is safe to say that 6 cubic feet per second, that might have been saved in a lined canal, was lost in the first 5 miles. This loss of $75 per day for the seventy-seven days would be $5,775—28½ per cent more than the cost of lining 1 mile. It seems evident, therefore, that as the citrus groves increase in number and value, the company would be well repaid for the expenditure incurred by lining the ditch with cement mortar.

SUMMARY.

The duty of water and the return per acre-foot, which have been worked out above, are summarized in the following table. As the water supply for the season of 1901 was so unusually large, the percentage of unused water must have been correspondingly great. Therefore the duty of water, when the measurement was taken at the head of the ditch, is not a fair one. Our averages show that the depth of irrigation for citrus trees varies from 1 to 2 feet. A depth of 1.5 feet for full-bearing trees on adobe or loam soil seems a sufficient allowance where the rainfall is 10 inches.

Duty of water and return per acre-foot under Tule River ditches, 1901.

Source.	Period.	General duty.		Return per acre-foot.
		Depth of irrigation.	Depth with rainfall.	
Plano Ditch	Apr. 27–Nov. 8 [a]	7.91	8.29	
Poplar Ditch	Apr. 11–July 6 [a]	3.19	3.50	
Pioneer Ditch:				
Measurement at head	May 19–Nov. 8 [a]	8.01	8.23	
Company's record	Entire year	3.19	4.03	$27.61
Citrus groves	do	2.00	2.84	79.08
Alfalfa and deciduous trees	Mar. 27–Aug. 3	1.41	1.78	24.37
Pleasant Valley:				
Measurement at head	Apr. 21–Oct. 11	6.31	6.66	8.56
Sprott citrus groves	July–Oct	1.55	1.62	63.79
South Tule Independent, measurement at head	May 8–Oct. 31	7.46	7.68	10.63
Lindsay Water Development Co., citrus groves:				
1898		1.00	[b] 1.47	
1899		1.63	[b] 2.23	
1900		1.50	[b] 2.35	
1901		1.14	[b] 1.98	

[a] Time covered by measurements, not entire season.
[b] Rainfall for entire year used.

LITIGATION.

Though it is not the province of this report to go into the question of water rights, yet the duty of water seems to be so affected by the indifference to another's weal rising out of court troubles that a brief summary of the lawsuits is given.

JONES *v.* POPLAR.

The first ditch to become involved in litigation was the Poplar. In March, 1881, the Jones Ditch secured a perpetual injunction against it, but the injunction was never maintained and is now considered void by limitation.

HUBBS & MINER AND FINE *v.* POPLAR.

On April 9, 1900, a temporary injunction was granted restraining the Poplar Ditch from taking water from Tule River until the Hubbs & Miner Ditch had 15 cubic feet per second, and the Fine Ditch, 10 cubic feet per second. The suit is now pending.

PLANO *v.* PIONEER.

As the result of a suit against the Pioneer Ditch, the Plano Ditch was granted a prior right to 20 cubic feet per second, December 6, 1892. Since that time the Pioneer Land Company has acquired 127 of the 256 shares of the Plano Ditch, and with the assistance of other irrigators under the Pioneer Ditch is able to vote 130 shares. By a court decree of April 1, 1900, the Pioneer Land Company was allowed to divert its share of the 20 cubic feet per second, granted to the Plano Ditch, through the Pioneer Canal. During the summer of 1901 the attorney of the Pioneer Land Company commenced proceedings to dissolve the Plano Ditch Company. It is now expected that the suit will be settled out of court and the stock owners on the north side of the river granted two-thirds of the 20 cubic feet per second priority.

ANGIOLA CANAL *v.* TIPTON IRRIGATION DISTRICT CANAL.

The Tipton Irrigation district was able to use its expensive system only for the first two years after construction. On September 10, 1895, the district was enjoined by C. W. Clark, of the Angiola Canal Company, Lower Tule River, from taking water from the river. The district organization is now dead.

HUBBS & MINER *v.* PIONEER.

Besides the suit against the Poplar Ditch, the Hubbs & Miner Ditch directors have been involved with the Pioneer Canal Company. On December 7, 1898, the Hubbs & Miner secured judgment against the Pioneer for 30 cubic feet per second. The Pioneer Canal later received a reversal of the decision, awarding it 15 cubic feet per second. The case is not yet settled.

PIONEER *v.* PLEASANT VALLEY.

The Pioneer Ditch sued the Pleasant Valley Ditch several years ago and the case was finally settled out of court during the summer of 1900. The Pleasant Valley Ditch was allowed a priority of 2½ cubic feet per second and judgment was entered accordingly.

PIONEER DITCH HEAD GATE.

VANDALIA *v.* PIONEER.

The Vandalia Ditch instituted suit during the fall of 1901 for a prior right of 15 cubic feet per second against the Pioneer Canal. The case has not yet been tried.

FINE *v.* PIONEER.

The Fine Ditch commenced proceedings against the Pioneer Canal during the summer of 1901 on a claim of a prior right to 30 cubic feet per second. No hearing has thus far been given.

PIONEER *v.* SMALL DITCHES.

Beside the many cases mentioned above in which the Pioneer Canal has figured, it is about to begin suit against all the small ditches above it on the river, with the exception of the Pleasant Valley Ditch, to quiet title to water. Under the present system in California, the only way a ditch company can be sure of its rights is to secure a court decree against every other ditch, and even this does not quiet title as against later appropriators. This is the plan of the Pioneer Canal Company.

SOUTH TULE *v.* KING.

In 1899 the South Tule Independent Ditch instituted suit to restrain the owner of the King Ditch from meddling with its diverting dam. The case was first decided in favor of the plaintiff, but after a rehearing the King Ditch was granted a prior right to one-half cubic foot per second. The South Tule Independent directors believe that, owing to the unfavorable condition of the stream bed, they would have to let 1½ cubic feet per second pass the head of their ditch in order to leave one-half cubic foot per second at the head of the King Ditch. They are therefore not satisfied with the decree and have carried the case to the Supreme Court.

The relations of the owners of the better ditches are thus shown to be anything but amicable. Night raids and the destruction of the higher diverting and wing dams by parties wishing the water below are not unusual. The Pioneer Company has been forced to retain armed men at its head gate throughout the season of scarcity. (Pl. XXXI.) The great majority of ditch men deprecate the condition of affairs, and have often expressed fervent wishes that the State or Federal Government might undertake the equitable division of the stream.

WASHINGTON.

THE USE OF WATER IN IRRIGATION IN WASHINGTON FOR THE SEASON OF 1901.

By O. L. Waller,

Irrigation Engineer, Washington Agricultural Experiment Station.

The work discussed in this report is a continuation of the work done and reported on in 1900.[a] That report contained a general description of the Sunnyside Canal and country, also of the soil, its formation, etc. The plant at Prosser was described and such general information given concerning the country, soil, and other features as seemed necessary to make the irrigation conditions plain to the reader. For these reasons all such matter is omitted in this report.

PROSSER CANAL.

EVAPORATION AND RAINFALL.

The following tables give the results of measurements of rainfall and evaporation at Prosser, Wash., for the irrigation season of 1901:

Rainfall at Prosser, Wash., 1901.

Date.	Inches.	Date.	Inches.
May 17	0.10	September 8	0.27
May 19	.29	September 16	.34
May 23	.07		
June 19	.20	Total	1.73
September 1	.46		

Measured evaporation at Prosser, Wash., 1901.

Period ending—	Inches.	Period ending—	Inches.
April 22	1.2	August 13	2.0
May 18	1.7	August 26	2.7
May 26	.9	September 16	2.5
June 3	1.0	September 30	1.3
June 10	1.3	October 14	2.6
June 17	1.0	October 28	2.0
June 24	1.5		
July 7	2.5	Total	28.9
July 15	1.2	Plus rainfall	1.73
July 22	1.5		
July 29	2.0	Total evaporation	30.63

[a] U. S. Dept. Agr., Office of Experiment Stations Bul. 104.

WATER SUPPLY.

Water for irrigation under the Prosser Canal is lifted by two pumps, having a capacity of 27.27 cubic feet per revolution per pump, or a total capacity of 54.54 cubic feet per revolution. These pumps are both equipped with automatic registers which record the number of revolutions. The plunger displacement for the irrigation season was equal to 5,641.3 acre-feet after 5 per cent was deducted for slip. To determine this factor, one end of the pumps was removed and the slippage measured. From the way the record was kept it was difficult to apportion the amount lifted by months. However, a fair estimate may be gotten by consulting the discharge table of the west ditch, given below. The water from the pumps is forced through 1,800 feet of 30-inch riveted pipe to a penstock, from which it is carried a short distance in a canal. The canal then divides, one branch running east and the other west. A flume was placed in the west ditch and the depth of water registered for the season. The following table gives the discharge of this flume:

Discharge of the west line of the Prosser Ditch for the irrigation season of 1901.

Day.	April.	May.	June.	July.	August.	September.	October.
	Acre-feet.	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*
1	....	15.96	14.08	16.32	16.01	13.92	15.11
2	....	15.98	13.78	15.93	17.01	13.76	14.03
3	....	16.12	19.35	15.72	16.14	14.61	14.00
4	....	16.14	10.14	15.96	15.73	17.13	13.90
5	....	16.08	14.35	16.14	15.72	16.85	14.08
6	....	16.04	15.40	16.02	15.72	17.78	14.16
7	14.16	15.51	15.84	15.18	15.96	17.39	14.26
8	14.07	13.63	15.90	15.12	15.84	17.88	14.10
9	15.80	14.64	16.08	15.12	15.51	18.24	11.07
10	35.51	14.40	15.54	13.04	15.54	17.35	14.76
11	31.18	14.80	11.20	15.48	15.12	17.84	14.76
12	18.70	15.12	10.59	15.72	14.73	17.64	14.76
13	17.47	15.05	15.66	16.04	15.36	17.52	14.61
14	15.45	15.00	15.84	16.32	14.71	17.63	13.88
15	15.55	15.00	15.74	16.05	15.48	18.24	14.18
16	15.00	13.50	15.00	16.65	15.36	18.10	10.86
17	14.88	15.00	15.05	17.16	15.00	17.88	13.56
18	14.88	15.42	15.93	16.80	15.12	17.90	13.62
19	14.88	15.96	15.36	16.44	15.73	17.90	14.18
20	14.94	15.96	15.17	15.92	15.96	17.90	14.76
21	16.20	15.96	15.72	15.00	16.32	13.87	14.40
22	16.30	15.95	15.00	14.10	16.22	14.16	14.23
23	16.32	15.95	15.12	12.33	16.06	14.04	15.03
24	15.96	15.95	15.36	12.58	16.14	14.55	14.49
25	16.08	15.94	16.05	13.05	15.84	14.50	14.26
26	16.33	15.00	16.25	13.41	15.36	13.92	14.81
27	16.24	15.36	16.56	14.96	15.09	14.04	14.96
28	16.20	15.12	16.57	15.57	15.13	15.22	14.52
29	16.31	15.00	16.44	16.37	15.24	15.12	13.77
30	15.84	14.30	16.32	16.28	14.40	15.36	13.68
31	....	14.10	....	15.17	14.30	....	9.60
Total	414.25	473.94	455.39	475.95	481.85	487.24	432.39

This water was used upon 885 acres of cultivated crops and trees and lawns in the town, being sufficient to cover that area to a depth of 3.53 feet. Including the rainfall during the season, this land received water enough to cover it to a depth of 3.67 feet. The total supply from the pumps, 5,641.3 acre-feet, served 1,201 acres, giving a depth of 4.7 feet, or, with the rainfall, 4.85 feet. Deducting from the above totals the measurements given for the west ditch, leaves 2,520.3 acre-feet of water for the east ditch, and 316 acres

served by this flow. This gives a depth of irrigation of 7.98 feet, or 8.12 feet, including rainfall. Considering the gravel subsoil of the lands under the east ditch, it is only fair that they should receive more water than the other lands served, but hardly at the rate here shown. The contracts call for no more water than those for other lands. This condition of affairs can be easily remedied by putting in suitable gates where the main ditch branches.

Some of the results of farming under the Prosser Canal are given below.

FARM OF MAURICE EVANS.

The water supply for Mr. Maurice Evans was measured over a 12-inch Cippoletti weir. The readings were taken every day. The head was very uniform and the results may be relied upon as approximately correct. On 31 acres farmed Mr. Evans used 111.16 acre-feet, estimating the discharge from April 1 to 11, before the weir was placed. This would give a depth of 3.72 feet, including rainfall. The gauge readings showed so little variation, we may assume that the same amount was used each month and therefore omit showing the use by months.

Mr. Evans furnished the following statement of his season's work:

I farmed this year under the Prosser Canal 36 acres, of which 25 acres is in alfalfa. The first cutting from that 25 acres I baled and shipped at once, selling it at $6.50 per ton on cars. It baled out 100 tons even besides a little we fed. The second cutting measured 104 tons by the usual rule of measuring hay after thirty days in stack. We called that 100 tons. I sold it in stack at $4. The third cutting measured out 50 tons. I sold 40 and kept 10 to feed three horses and two cows until hay comes next year. Thus the 25 acres has yielded 10 tons per acre, besides some that has been fed. I had 1¼ acres in potatoes; dug them early and shipped 160 sacks (about 100 pounds each), receiving $21 a ton on cars for the 8 tons, $168. I had 4 tons of small potatoes left, which we sold locally and fed. I then planted the same ground to turnips, and have harvested 100 sacks of turnips. Have already sold 80 sacks at 60 cents, $48, and am keeping the rest for my own use. I have been offered 75 cents per sack. Calling the 100 sacks of turnips, at 60 cents, $60, plus $168 for potatoes, equals $228 from 1¼ acres. I am satisfied that with good cultivation I can double the potato yield.

CAMPBELL FARM.

Crop report of the Campbell farm under the Prosser Ditch, 1901.

18 acres of alfalfa	tons..	210
1½ acres of clover	do....	7
12 acres of melons	melons..	10,000
¼ acre of beans	pounds..	400
$\frac{1}{16}$ acre of cantaloupe	crates..	34
½ acre of potatoes	tons..	3
½ acre of sweet corn	sacks..	40
⅛ acre of carrots	tons..	3
$\frac{1}{16}$ acre of strawberries	crates..	20
1½ acres of pasture which kept 2 horses and 2 cows all summer, fall pasture on hay fields, worth	dollars..	75
7 stands of bees, honey	pounds..	300
2 hogs, undressed	do....	600
Poultry and eggs for family use.		

RATTLESNAKE RANCHES.

The Rattlesnake ranches owned by Mr. E. F. Benson are watered by springs, known as the Upper and Lower Rattlesnakes. On March 28, 1901, the lower spring gauged 0.95 cubic foot per second about 1 mile above where it enters the irrigated fields and about 2½ miles below where it flows from the rocks. This would make a supply of 270.8 acre-feet for the season, giving a depth of 4.6 feet on the 59 acres under cultivation. The lower ranch for 1901 yielded as follows: Twenty-three acres of alfalfa yielded 145 tons; 30 acres of spring wheat yielded 50 tons of hay; 3 acres in garden and orchard; 3 acres in pasture for work horses, 8 head of cows, and a few sheep for summer mutton.

It should be said that owing to the making of a new ditch, water was not put onto this ground until late.

The water from the upper spring is piped to the point of use. At this point it measured 0.163 cubic foot per second. The season's supply would then be 49.8 acre-feet, or a depth of 3.11 feet for the 16 acres under cultivation. Mr. Benson reports the crop as follows: One hundred and twenty-eight tons of alfalfa from 16 acres. This was sold in the stack at $6 per ton. The 14 acres in wheat did not get much water and turned off only about 1 ton per acre. This was used to feed farm teams. The alfalfa field made fine pasture for cattle from November 1 to December 10, 1901.

JORDAN ORCHARD.

Register No. 30 was placed on the supply to the Jordan orchard. This tract contained 20 acres, 12 acres of which was in orchard, 6 acres in alfalfa, and the balance in garden and yard. The 6 acres of alfalfa yielded 50 tons of hay. From the orchard 5,000 boxes of winter apples were picked. Besides this, $500 worth of other fruit was sold. The following table shows the water used on the farm:

Daily discharge, Jordan's orchard weir, Jordan's ranch, near Prosser, season of 1901.

Day.	May.	June.	July.	August.	September.
	Acre-feet.	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*
1	0.35	0.96	1.31	1.51	0.60
2	.25	1.14	.62	1.36	.55
3	.47	1.34	.60	1.32	.53
4	.35	1.32	.63	1.30	.56
5	.28	1.46	.89	1.21	.52
6	.35	1.53	1.10	1.01	.34
7	.14	1.44	1.10	1.12	.37
8	.43	1.10	1.10	1.52	.43
9	.29	1.02	1.16	1.66	.43
10	.18	.91	1.21	1.80	.43
11	.43	.75	1.21	1.88	.24
12	.39	.71	1.21	1.72	.35
13		.69	1.01	1.42	.31
14		.44	1.45	1.15	.26
15		.30	1.66	1.00	
16	.15	.08	.81	1.02	
17	.20		.87	1.15	

Daily discharge, Jordan's orchard weir, Jordan's ranch, near Prosser, etc.—Continued.

Day.	May.	June.	July.	August.	September.
	Acre-feet.	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*
18	0.30		0.60	1.12	
19	.62	0.16	.64	1.13	
20	.77	.86	.57	1.00	
21	.81	.84	.64	.96	
22	.84	.99	.64	.95	
23	.84	1.88	.65	.60	
24	.81	1.95	1.00	.05	
25	.84	1.79	1.66	.75	
26	.84	1.61	1.82	1.12	
27	.82	1.41	2.04	.71	
28	.94	1.44	1.80	.35	
29	.92	1.23	1.75	.42	
30	.87	1.34	1.77	.53	
31	.92		1.78	.47	
Total	15.40	30.59	35.33	33.31	5.92

The total water used was 120.55 acre-feet, making an average depth of 6.03 feet on the 20 acres irrigated.

SUNNYSIDE CANAL.

The evaporation and rainfall for the irrigating season of 1901, at Zillah, near the head of the Sunnyside Canal, are given in the following table:

Evaporation and rainfall on W. N. Granger's place, near Zillah, Wash., season of 1901.

Week ending—	Evaporation.	Rainfall.	Week ending—	Evaporation.	Rainfall.
	Inches.	*Inches.*		*Inches.*	*Inches.*
June 8	1.60	0.05	August 31	2.25	0.25
June 15	1.20	.90	September 7	1.15	.00
June 22	2.15	.00	September 14	.60	.00
June 29	1.48	.10	September 21	.56	.00
July 7	1.52	.00	September 28	.57	.00
July 13	1.60	.02	October 5	.37	.00
July 20	1.95	.00	October 12	.37	.10
July 27	2.00	.00	October 19	.37	.00
August 3	1.50	.00	October 26	.37	.00
August 10	1.50	.00	November 2	.23	.00
August 17	1.50	.00			
August 24	2.25	.50	Total	27.09	1.92

The following table gives the daily flow of Sunnyside Canal for the irrigating season of 1901:

Daily discharge of the Sunnyside Canal, season of 1901.

Day.	April.	May.	June.	July.	August.	September.	October.
	Acre-feet.	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*
1	158.5	537.0	648.0	911.0	836.0	1,034.0	471.0
2	194.2	571.0	648.0	911.0	970.0	857.0	471.0
3	194.2	608.0	667.0	911.0	1,000.0	857.0	471.0
4	194.2	648.0	627.0	911.0	1,034.0	780.0	685.0
5	194.2	688.0	647.0	911.0	1,034.0	766.0	685.0
6	194.2	707.0	647.0	940.0	1,034.0	766.0	503.0
7	158.5	726.8	667.0	970.0	1,069.0	639.0	503.0
8	234.0	816.0	687.0	970.0	1,069.0	570.0	503.0
9	234.0	816.0	687.0	1,034.0	1,069.0	571.0	503.0
10	250.0	816.0	687.0	1,034.0	1,108.0	571.0	503.0

Daily discharge of the Sunnyside Canal, season of 1901—Continued.

Day.	April.	May.	June.	July.	August.	September.	October.
	Acre-feet.	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*
11	....	835.0	687.0	1,034.0	1,069.0	608.0	503.0
12	....	....	687.0	1,034.0	1,108.0	608.0	518.0
13	....	....	648.0	1,034.0	1,108.0	608.0	536.0
14	273.0	....	590.0	1,034.0	1,108.0	608.0	536.0
15	273.0	648.0	590.0	1,034.0	1,108.0	608.0	536.0
16	273.0	571.0	590.0	1,034.0	1,108.0	608.0	536.0
17	313.0	648.0	571.0	1,034.0	1,108.0	648.0	536.0
18	257.0	627.0	571.0	1,000.0	1,108.0	648.0	536.0
19	382.0	627.0	608.0	1,000.0	1,108.0	648.0	536.0
20	503.0	627.0	648.0	1,000.0	1,108.0	726.0	536.0
21	571.0	627.0	648.0	1,000.0	1,108.0	687.0	536.0
22	357.0	627.0	687.0	970.0	1,108.0	687.0	536.0
23	337.5	627.0	766.0	1,000.0	1,108.0	716.0	536.0
24	571.0	627.0	766.0	....	1,069.0	687.0	503.0
25	....	648.0	766.0	518.0	1,069.0	687.0	503.0
26	69.3	608.0	816.0	911.0	1,069.0	234.0	503.0
27	141.0	648.0	816.0	911.0	1,069.0	571.0	536.0
28	174.5	648.0	857.0	911.0	1,069.0	571.0	536.0
29	273.0	648.0	857.0	857.0	1,089.0	564.0	536.0
30	410.0	648.0	911.0	1,000.0	1,049.0	....	503.0
31	....	648.0	....	1,183.0	1,049.0	....	471.0
Total	7,184.3	18,520.8	20,692.0	29,002.0	33,120.0	19,133.0	16,306.0

The total acreage watered by the Sunnyside Canal during 1901, together with the areas devoted to the various crops, is as follows:

Crops irrigated under Sunnyside Canal, 1901.

	Acres.
Alfalfa	7,621.7
Timothy and clover	2,867.2
Orchard	2,179.3
Corn	527.5
Potatoes	505.4
Garden	282.1
Hops	382.1
Miscellaneous	598.7
Total	14,964.0

Duty of water under Sunnyside Canal, 1901.

Area irrigated	acres..	14,964.00
Water used	acre-feet..	145,958.10
Depth of water used in irrigation	feet..	9.75
Depth of rainfall	foot..	.16
Total depth of water received by land	feet..	9.91

Measurements were also made on two tracts under the Sunnyside Canal. The results are given below:

DUNN HOPYARD.

Capt. R. D. Dunn's hopyard contains 38 acres and yielded in 1901 29 tons of hops. The following table gives the quantities of water used daily in the hopyard:

FIG. 1.—A SYSTEM OF HEAD DITCHES.

FIG. 2.—SAME SYSTEM OF HEAD DITCHES.

FIG. 3.—GAUGING A LATERAL.

FIG. 4.—GAUGING MAIN CANAL JUST PELOW THE HEAD GATE.

Daily discharge of Dunn lateral of Sunnyside Canal, 1901.

Day.	May.	June.	July.	August.
	Acre-feet.	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*
1	....	1.53	1.39	1.38
2	....	1.51	1.44	1.54
3	....	.39	1.44	1.59
4	....	Water out.	1.48	1.63
5	0.44	....	1.49	1.44
6	.65	....	1.60	1.49
7	.59	....	1.66	1.39
8	1.05	....	1.66	1.38
9	1.53	....	1.56	1.33
10	1.92	....	1.56	.44
11	1.90	....	1.43	....
12	1.79	....	1.47	....
13	.12	.45	1.60	....
14	.13	.95	1.60	....
15	1.18	.33	1.56	....
16	1.60	....	1.50	....
17	1.80	....	1.50	....
18	1.17	....	1.44	....
19	.80	.52	1.38	.39
20	.76	1.04	1.72	1.56
21	.81	1.17	1.75	1.53
22	.89	1.40	1.70	1.45
23	.78	1.81	1.39	1.24
24	.78	1.64	.99	1.21
25	.82	1.32	1.55	1.12
26	1.95	1.18	1.66	1.25
27	1.95	1.24	1.42	1.38
28	2.05	1.39	1.08	1.38
29	2.04	1.44	1.56	1.38
30	1.92	1.44	1.48	1.38
31	1.73	....	1.45	1.20
Total	33.15	20.75	46.51	30.08

A total of 130.49 acre-feet of water was used, enough to cover the land to a depth of 3.43 feet. Captain Dunn states that this is double the quantity of water used in any previous season, while the crop is 1,500 pounds short of the crop of 1900. Owing to a deposit of silt in the distributing ditches, much of the water ran off the field. Half the field was subsoiled to a depth of 16 inches. This part of the field yielded small, undeveloped cones, and it is thought that the subsoiling damaged the roots of the hops. The part of the field which was not subsoiled yielded a large crop of good quality.

R. D. YOUNG FARM.

This farm is on a ridge and well above any surrounding land. Mr. Young gets his supply from the Snipes Mountain lateral through 3,509 feet of 8-inch riveted pipe, laid as an inverted siphon. This pipe, when rated, carried 0.95 cubic foot per second. Its computed capacity at the time of laying it was 1.04 cubic feet per second. During this season all of this water was used on 38 acres of land, planted as follows: Orchard, not bearing, 18 acres; alfalfa, 17 acres, yielded 125 tons; clover, 2 acres, yielded 10 tons; lawn, 1 acre.

During the last half of June, all of July and August, and the first half of September the hay land required and used nearly all the water.

This would cover the whole area irrigated to a depth of 10.61 feet, and during the period when the hay got all of it, the quantity used on the hay land would have been about doubled. This seems like an excessive use of water, yet Mr. Young feels that he does not get water enough and is studying methods of irrigating so that he may not only save all the water furnished but get as large returns as possible from it. Lands immediately adjoining are not irrigated; consequently this land gets nothing from subirrigation, as most of the lands about Sunnyside do. Mr. Young will likely put in more head ditches and shorten the furrows.

IDAHO.

THE DISTRIBUTION OF WATER FROM CANALS IN IDAHO.

By D. W. Ross, *State Engineer.*

The studies of the quantities of water used in maturing crops in Idaho, which have been carried on for the past few years, have led to the conclusion that the regulations under which water is delivered to farmers have a controlling influence on the quantities used. The measurements made in the Boise Valley during the season of 1901 have had especial reference to this point. The experiences of the Boise City Land and Irrigation Company and of some other companies are discussed in this paper.

OBSERVATIONS IN BOISE VALLEY.

The Boise City Land and Irrigation Company's Canal, commonly known as the "Ridenbaugh" Canal, is the principal canal of the Boise Valley, covering from 75,000 to 100,000 acres of irrigable land and irrigating about 22,500 acres. This is one of the few canals in the State operating under what is commonly called a "rental" system; that is, charging a fixed amount for the work of diverting water from the stream and conducting it to the land where it is distributed to the irrigators.

The present system is the result of a slow growth from small beginnings, and, like all irrigation systems developed in this manner, certain practices of the early irrigators, the result of certain provisions in contracts drawn by men without experience in the subject of irrigation, have attained in a comparatively short time practically all the force of customs which, although very detrimental to the best interests of the valley, like every custom once established, have caused much trouble to those desirous of adopting better methods.

This canal system was begun in 1878. In 1890 the small ditch, which then was about 13 miles long, with a capacity of about 30 cubic feet per second, was enlarged and extended. Extensions and enlargements have been made since that time until the main canal is now about 50 miles long, with a capacity in its upper portion of about 420 cubic feet per second. Nearly 200 miles of main laterals have also been constructed and added to the system.

The relations between irrigator and ditch owner have varied according to the nature of the contracts outstanding. In the early years of the enterprise "perpetual water rights" were sold at the rate of $10 per acre, with an annual maintenance charge, varying all the way from 25 cents to $1 per acre. Some of these rights were set aside by mutual agreement, many as a result of foreclosure proceedings and reorganization of the company. Water rights of this nature recognized by the company amount to 62.25 cubic feet per second. None of these has been entered into since 1897. Before that year all users were obliged to purchase a so-called water right which provided that the charge for delivering the water or "maintenance," as it was called, should be at the rate of a certain amount per acre for the land irrigated. Later on it was determined that it was not necessary to purchase a "water right," but that any landowner was entitled to have water delivered to him if it was in the canal, upon payment of the charges made or established by the proper authorities. Applications for water were, therefore, received by the company up to the extent of the capacity of the canal, the charge for its delivery being at the rate of $1.50 per acre, following to this extent the practice established by the terms of the water-right contracts referred to.

Up to this time there had been no attempt made toward economy in the use of water. But with practically an unlimited area of irrigable land in the valley susceptible of reclamation (about 310,000 acres) and a water supply varying from over 40,000 cubic feet per second during June of some years to less than 700 cubic feet per second in August of others, it became evident that, with the area under cultivation increasing each year, methods of economy would have to be adopted, which is probably the easiest, if not the cheapest, means of increasing the natural water supply under any conditions which might prevail in an irrigated section.

With this object in view the company referred to fixed a price for the delivery of water during the irrigating season of 1899 at the rate of $75 per cubic foot per second. The notice to customers stated that applications made on the company's contract forms would be required of all customers, "whether claiming water-right agreements or under general rental." A suggestion was at the same time made to customers, "that under the present law it was very desirable, if not absolutely necessary, for customers under a common lateral, in order to use the water to the best advantage, to club together on a system of rotation; also that all laterals be kept thoroughly clean and banks strengthened to prevent overflow or waste."

The suggestion made here, that irrigators "club together and use their water in turn or rotation," was adopted by some as an experiment; but the majority of water users preferred to have a stream flowing continuously. It was not so troublesome. They always knew

where their water was. If they did not need it, it did no harm if allowed to run through their laterals out into the brush.

The management soon realized, however, that this agreement to deliver a given head of water for the entire season could never become a permanent system, for the very simple reason that they were then distributing, during the months of August and September, the low-water stage of the river, their probable share of the flow of the stream—about 275 cubic feet per second, when it shall have been finally allotted by the court—while their plans contemplated the enlargement of their main canal to a capacity of from 1,200 to 1,500 cubic feet per second. An attempt was therefore made in 1901 to devise a system of distribution which would adjust itself to the conditions surrounding the water supply and which would be equitable and just to all, as well as permanent.

The basis of the system adopted was in charging for the delivery of water according to the amount used. This charge was at the rate of 1½ cents per inch of water (an inch being the one-fiftieth part of a cubic foot per second) per day of twenty-four hours.

The following is the form of the application required to be made by the irrigators under this system:

CONTRACT.

In consideration of the agreement of The Boise City Irrigation and Land Company, as herein set forth, I, ——— ———, hereby apply for the use of, and agree to take, water, as below specified, from The Boise City Irrigation and Land Company's Canal, for the irrigation season of 1902, for irrigation and domestic purposes only, to be used on the —— sec. ——, twp. ——, range ——, and for no other land, the said company reserving the right to gather and utilize the water running away from said land.

Said water so applied for to be delivered at the lateral head gate of said canal, No. ——, located in the —— sec. ——, twp. ——, range ——, or at the weirs of the company's drain ditches running into said lateral.

And I hereby agree to pay said The Boise City Irrigation and Land Company, at its office, for said water, the sum of one and one-half (1½) cents per miner's inch per day (twenty-four hours), a miner's inch being called equal to one-fiftieth ($\frac{1}{50}$) of 1 cubic foot per second.

The aggregate amount for water so used at said rate during the irrigation season, being due and payable November 1, 1902, with interest thereon at 10 per cent per annum, from time when due to time of payment; and it is further agreed that until said rental is paid, no demand or claim shall be good against said canal for water for said land for any succeeding season.

The Boise City Irrigation and Land Company, in consideration of the foregoing agreement on the part of ———, hereby agrees to deliver the water as aforesaid, unforeseen and unavoidable accidents and conditions excepted, as the said ——— may require, but at no time shall the maximum flow demanded exceed —— miner's inches per day.

The said canal company reserves the right in any emergency or shortage of water beyond its control to rotate the delivery of water at its lateral head gates.

Witness: ——— ———.

——— ———

THE BOISE CITY IRRIGATION AND LAND COMPANY,
By ——— ———, *Manager.*

While the above application appears to limit the size of the head allowed, it does not in practice do so. The provision is for the purpose of determining the probable demand for the season and not with a view of restricting the irrigator in the use of water, as he is given practically any sized head he may desire.

Most of the main laterals under this system belong to and are operated by the company. These laterals are under the control of the company's water masters, who receive orders for water from the irrigators. The manner of using water is left very largely to the irrigators—that is, they order any volume which they may think best. Some of them take large heads, or the entire stream flowing in their common lateral in turn, while the heads used by others vary from time to time.

The adoption of this system was not, however, an easy matter. The objections were many and came principally from the older irrigators. They urged that "rotation" was simply a fad of the hour, an innovation suggested by the theorist, that it was absolutely necessary to have a stream flowing continuously, the cost of delivering which, at the rate proposed, would be ruinous, many asserting that it would amount to from $2 to $5 per acre each season.

By the terms of the former contracts the charge for the delivery of water was based upon the continuous flow of the stream contracted for, which, as a matter of course, had been allowed to flow in that manner. Under this arrangement the best evidence that the irrigator was not receiving fair treatment was the inability of the company to keep his full supply of water running, no matter whether it had a right to divert water from the river or not. It was not astonishing then that the value of a "water right" should, in the minds of some irrigators, depend upon the continuity of the flow of their irrigating stream, rather than the right to the use of a certain depth of water over their land—enough to produce crops—to be delivered during the season as they might desire.

Assuming that it would be necessary to use continuously throughout the season the maximum head required, the rate proposed would of course be exorbitant. Based, however, upon the average depth of water required for growing crops, the rates would be reasonable. They would not, however, be uniform, but would vary with the soil, slope of the ground, the kind of crops, and the care and skill of the irrigator.

Proceeding upon the theory that the continuous flow of an irrigating stream was necessary, and that the rate proposed by the company was unreasonable, a protest was made by many of the irrigators against the action of the company, and the board of county commissioners was petitioned to fix a reasonable rate for the distribution of water for the season. This petition was heard by the commissioners on February 16, 1901, the only evidence submitted relating to the rates previously charged by the company. After hearing the petition and

evidence the board fixed the rate at \$75 per cubic foot per second flowing continuously throughout the irrigation season.

An appeal was taken from the order of the commissioners to the district court, for a review of the proceedings. This appeal was taken upon the grounds that the effect of the order, if it were obeyed, would be the taking of the property of the company without due process of law. The court refused to review the case, but ordered it tried de novo. The complainants then petitioned the supreme court of the State, asking that a writ of mandamus be issued, ordering the district court to review the proceedings of the commissioners. This petition the higher court refused to grant, upon the grounds that the question at issue, the jurisdiction of the lower court, could be heard on an appeal taken in the ordinary manner. Later on, the appeal which had originally been made to the district court was asked to be dismissed, when the case was transferred to the United States court of the State of Idaho.

Pending the adjudication of the action of the board of county commissioners by the courts, several irrigators petitioned the district court to issue an order compelling the company to deliver water to them at the rate fixed by the board. The court complied with this request. Several other of the irrigators demanded a continuous flow of water under the provisions of the old water-right contracts referred to; while others, acting under the advice of their lawyers, made a similar request. These demands called for the delivery in this manner of about one-half the capacity of the canal, so that about one-half of the irrigators of the district were paying for the delivery of their water at the rate of 1¼ cents per 24-hour inch, delivered at intervals in such heads as they desired, while water was delivered to the other half continuously at the rate of \$75 per cubic foot per second, pending the fixing of a rate by the court. Water was measured from the main canal to all users alike, regardless of the arrangements which had been entered into. Trapezoidal weirs were used in nearly every case. These weirs were carefully constructed and fitted with gauges, from a simple inspection of which the amount flowing at any stage could be found. The volume discharged over these weirs was noted twice each day by the water master, and since the gauges could always be seen plainly by the irrigators themselves, there is no doubt but what the records kept were very accurate and reliable. On some of these laterals these records were kept by a water master appointed by the irrigators themselves. Registers for recording the depth of water flowing over a weir were used on the Hunter and Tuttle laterals.

In order to make a comparison of the various systems of distribution practiced, several laterals were selected where the irrigators practiced close economy, the water being used in rotation, in such heads as they deemed best.

The lands irrigated in this manner from these laterals amounted to 1,269 acres. There were thirty-six users, who applied an average depth of 4.14 feet over this area. In the case of the Creeson lateral, from which there was irrigated 924 acres, by twenty-four users, rotation was not followed strictly, but only generally. The average depth used in this case was considerable greater than where rotation was strictly followed, being 4.48 feet in depth, against 2.55 to 3.80 feet used by those practicing rotation.

Four laterals were selected from which a part of the water was used in rotation, the remainder having been divided into heads which were allowed to flow all the time. The lands irrigated by these laterals embraced an area of 1,984 acres, using in all 8,869.72 acre-feet of water, or an average depth of 4.47 feet. This land belonged to sixty-one users.

The system of continuous flow is illustrated by the records of four laterals which irrigated 1,461 acres belonging to forty-three users. There was delivered to these lands 8,489.18 acre-feet, making an average depth of 5.81 feet. Most of these users demanded that their irrigating streams be allowed to flow continuously, many of them at the advice of their lawyers.

The following tables show the use of water each day during the irrigating seasons from the laterals referred to:

Use of water from the Crawford lateral on the land of G. Blackstock.

[40 acres irrigated, 5 other users. Distribution by rotation.]

Day.	April.	May.	June.	July.	August.	September.	October.
	Acre-feet.	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*
1				1.92		2.00	
2				1.92		2.00	
3				1.92		2.00	
4		2.24		1.92		2.00	
5		2.08	2.00	1.92		2.00	
6		2.08	2.00	1.92			
7			2.00				
8			2.00				
9			2.00		1.88		
10			2.00		1.92		
11			2.00		1.92		
12			2.00		1.92		4.36
13					1.92		4.36
14		2.24			1.92		4.36
15		2.08			1.92		
16		2.08			1.92		
17		2.08			1.92		
18		2.08		2.00	1.92		
19		2.08		2.00	1.92		
20		2.08		2.00	1.92		
21		2.08		2.00			
22		2.08		2.00			
23	0.84	1.00		2.00			
24	.84	1.00	2.40	2.00			
25	.70	1.00	2.40	2.00			
26	.24	1.00	2.40	2.00			
27	.24		2.40		2.00		
28	.42		2.40		2.00		
29	.48		2.40		2.00		
30	.48		2.40		2.00		
31					2.00		
Total	4.24	29.28	32.80	29.52	33.00	10.00	13.08

Use of water from the Crawford lateral on the land of W. G. McNeilly.

[65 acres irrigated, 5 other users. Distribution by rotation.]

Day.	April.	May.	June.	July.	August.	September.	October.
	Acre-feet.	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*
1				3.28			
2				3.28			
3				3.28			
4			4.00	3.28			
5			4.00	3.28		2.00	
6		4.20	4.00	3.28		4.00	
7		4.52	4.00	3.28	1.84	4.00	
8		4.00	4.00	3.28	1.84	4.00	
9		4.28	4.00	3.28	1.84	4.00	
10		4.28	4.00	3.28	1.84		
11		4.28	4.00	3.28	1.84		
12		4.04	4.00		1.84		
13		4.04			1.84		
14					1.84		
15					1.84		
16					1.84		
17					1.84		
18					1.84		
19					1.84		1.00
20				3.28	1.84		3.28
21		3.08		3.28	1.84		3.28
22		4.16		3.28	1.84		3.60
23	1.84	4.16		3.28	1.84		3.60
24	1.84	4.16		3.28	1.84		
25	1.55	4.16		3.28	1.84		
26	.54	4.16		3.28	1.84		
27	.54			3.28	1.84		
28	.94			3.28	1.84		
29	1.06				1.84		
30	1.06				1.84		
31					1.84		
Total	9.37	57.52	36.00	65.60	46.00	18.00	14.76

Use of water from the Crawford lateral on the land of J. H. Parks.

[30 acres irrigated, 5 other users. Distribution by rotation.]

Day.	April.	May.	June.	July.	August.	September.	October.
	Acre-feet.	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*
1			2.00				
2							
3					1.80		
4				1.12	1.88	2.00	
5				1.00	1.88	2.00	
6				1.00	1.88	2.00	
7				1.00	1.88	2.00	
8				1.20	1.88		
9		2.08		1.20			
10		2.08		1.20			
11		2.08		1.20			
12		1.96		1.20			
13		1.96	1.20	1.20			
14				1.20			
15			2.00	1.20			
16			2.00	1.20			
17			2.00	1.20			
18			2.00	2.12			
19				2.12			
20		2.00			2.00		
21		2.00			2.00		
22					2.00		
23	0.66				2.00		
24	.66				2.00		3.36
25	.56				2.00		3.36
26	.18				2.00		
27	.18	2.16			2.00		
28	.33	2.16		1.72			
29	.38	2.16		1.72			
30	.38	2.16		1.72			
31		2.16					
Total	3.33	24.96	11.20	25.52	27.20	8.00	6.72

Use of water from the Crawford lateral on the land of J. R. Fraser.

[30 acres irrigated, 5 other users. Distribution by rotation.]

Day.	April.	May.	June.	July.	August.	September.
	Acre-feet.	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*
1		2.32				1.20
2		1.92				1.20
3		1.92				1.20
4						1.20
5						1.20
6						1.20
7						1.20
8				0.96		1.20
9				.96		1.20
10				.96		.80
11				.96		
12				.96	0.96	
13			2.00	.96	.96	
14			2.00	.96	.96	
15		2.08		.96	.96	
16		2.08		.96	.96	
17		2.08		.96	1.00	
18		2.08			1.00	
19		2.08				
20						
21						
22						
23	0.70					
24	.70			1.00		
25	.58			1.00		
26	.20		2.00	1.00		
27	.20	2.08	2.00	1.00		
28	.35	2.08	2.00	1.00		
29	.40		2.00	1.16		
30	.40		2.00			
Total	3.53	20.72	14.00	15.76	6.80	11.60

Use of water from the Crawford lateral on the land of R. L. Blackstock.

[25 acres irrigated; 5 other users; distribution by rotation.]

Day.	April.	May.	June.	July.	August.
	Acre-feet.	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*
1					
2					1.92
3					1.92
4					1.92
5					1.92
6					2.00
7				2.00	2.00
8				2.04	
9				2.04	
10				2.04	
11				2.04	
12					
13			2.00		
14			2.00		
15			2.00		
16			2.00		
17			2.00		
18			1.00		
19			1.00		
20					
21					1.92
22					1.92
23	0.70			1.60	1.92
24	.70			1.60	1.92
25	.58			1.60	1.92
26	.20			1.60	1.92
27	.20			1.60	
28	.35			1.60	
29	.40	1.00		1.60	
30	.40	1.00		1.60	
Total	3.53	2.00	12.00	22.96	23.20

Use of water from the Crawford lateral on the land of M. E. Jones.

[25 acres irrigated; 5 other users; distribution by rotation.]

Day.	April.	May.	June.	July.	August.	September.	October.
	Acre-feet.	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*
1				1.64		1.00	
2						1.00	
3							
4		1.20					
5		1.04					
6							
7							
8							
9						1.00	
10						1.00	
11						1.00	
12		2.04			0.96		
13		2.04	2.00		.96		
14		2.28	2.00		.96		
15		2.08	2.00		.96		
16		2.08	2.00		.96		
17		2.08	2.00		.96		2.00
18		2.08	2.00	1.64	.96		2.00
19		2.08		1.64	1.00		
20				1.64	1.00		2.28
21				1.64	1.00		2.28
22				1.64			
23	0.42						
24	.42						
25	.35						
26	.12						
27	.12	2.00		1.64			
28	.21	2.00		1.64			
29	.24	2.00		1.64			
30	.24	2.00		1.64			
31		2.00		1.64			
Total	2.12	29.00	12.00	18.04	9.72	5.00	8.56

Use of water from the Huntington lateral.

[130 acres irrigated; 6 users; distribution by rotation.]

Day.	April.	May.	June.	July.	August.	September.
	Acre-feet.	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*
1		0.76	2.56	1.80	2.60	3.92
2		1.12	2.56	2.60	4.76	3.64
3		1.12	2.56	3.64	4.76	3.92
4		2.16	2.56		4.48	1.68
5		2.16	2.56	3.12	4.20	1.68
6		1.92	2.56	3.64	3.36	1.68
7		2.16	2.56		3.64	1.68
8		2.16	2.95	1.68	3.64	1.68
9		1.12	3.36	4.76	3.36	1.48
10		1.04	3.60	4.76	3.64	1.12
11		1.12	2.84	4.76	3.36	1.12
12		1.92	2.84	4.76	2.60	1.12
13		3.60	1.68	3.64	2.60	2.16
14		3.12	2.46	3.64	2.60	2.16
15		3.60	2.46	3.64	2.60	2.40
16		2.56	3.36		3.92	2.16
17		2.56	2.56		3.92	1.68
18		1.92	2.36	3.64	3.92	1.68
19		1.92	2.56	4.76	3.92	
20		1.92	3.88	4.76	3.92	1.68
21		.92	3.88	4.48	2.84	2.84
22		.92	3.88	3.82	1.68	2.84
23		.92	3.88	3.64	1.68	2.84
24		.76	3.36	3.12	1.68	2.60
25		.92	3.36	2.84	1.68	1.68
26		2.56	3.60	2.60	2.60	1.12
27		4.76	1.68	1.92	3.36	1.12
28	0.80	4.76	1.68		3.64	1.12
29	.80	3.92	1.92		3.64	1.32
30	.80	3.92	1.68	1.24	2.60	1.32
31		3.92		1.24	2.60	
Total	2.40	68.24	83.75	84.50	99.80	57.44

Use of water from the Creeson lateral.

[924 acres irrigated; 24 users; rotation general, but not perfect.]

Day.	May.	June.	July.	August.	September.	October.
	Acre-feet.	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*
1	....	28.56	25.52	32.84	27.36	16.40
2	25.56	28.56	27.72	31.72	29.88	15.32
3	19.20	30.64	27.80	28.24	32.20	16.40
4	19.76	27.28	27.80	28.24	26.92	15.32
5	22.84	29.00	29.88	18.68	23.08	11.12
6	30.52	26.88	29.32	28.24	21.76	11.12
7	20.76	22.72	26.24	26.04	20.04	13.12
8	16.60	13.48	22.00	26.04	19.56	15.32
9	19.20	28.12	14.32	27.16	18.76	15.32
10	24.52	24.32	....	29.32	18.76	15.32
11	14.20	24.32	30.32	27.16	19.56	15.32
12	21.08	28.56	25.84	27.72	22.16	17.60
13	14.84	31.20	24.76	26.04	23.40	20.16
14	18.72	31.20	17.72	29.88	22.16	17.60
15	18.72	30.28	25.48	27.72	25.48	17.60
16	22.44	30.28	24.40	28.24	25.48	15.32
17	25.08	23.96	21.32	28.24	25.48	5.40
18	29.68	24.32	22.40	28.84	22.16	10.64
19	29.68	27.40	19.52	29.92	22.56	10.64
20	29.44	24.12	29.92	27.72	22.56	9.08
21	29.84	24.12	30.92	27.72	22.56	10.64
22	29.84	24.68	31.72	27.72	25.48	10.64
23	32.08	25.80	29.44	27.72	26.88	9.08
24	28.04	26.88	28.08	23.48	15.68	7.68
25	29.00	27.92	28.08	27.72	15.68	7.68
26	31.28	27.92	28.12	27.72	14.40	....
27	35.12	26.88	9.08	27.72	15.68	....
28	28.60	24.68	29.48	26.60	17.00	....
29	30.16	26.88	31.72	27.72	15.36	....
30	30.16	25.76	18.88	27.72	16.24	....
31	29.04	....	12.12	27.72	....	....
Total	756.00	796.72	749.92	852.56	654.28	329.84

Use of water from Hunter lateral.

[683 acres irrigated; 20 users; distribution partly by rotation, partly by continuous flow.]

Day.	April.	May.	June.	July.	August.	September.	October.
	Acre-feet.	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*
1	....	4.64	22.00	17.52	20.00	21.88	10.48
2	....	9.92	17.40	21.88	22.60	21.88	10.48
3	....	9.92	....	23.76	22.60	21.88	10.48
4	....	9.92	20.16	21.88	19.00	13.48	4.20
5	....	11.48	22.00	16.68	19.00	13.48	4.20
6	....	11.48	22.00	21.88	19.00	13.48	4.20
7	....	11.48	22.00	21.00	20.00	13.48	4.20
8	....	12.32	22.00	21.00	20.00	13.48	4.20
9	....	12.32	24.00	22.80	20.00	13.48	4.20
10	....	11.48	24.00	15.00	20.00	13.48	4.20
11	....	13.92	26.08	15.00	20.00	13.48	2.28
12	....	15.60	26.08	21.00	20.80	13.48	2.28
13	....	15.60	27.16	19.24	20.80	13.48	2.28
14	....	20.12	16.48	17.52	21.60	13.48	2.28
15	....	20.12	13.16	13.48	21.60	13.48	2.28
16	....	22.08	13.16	20.12	21.60	13.48	7.76
17	....	22.08	20.16	21.00	21.60	10.48	7.76
18	....	20.12	20.16	21.00	21.60	10.48	7.76
19	....	18.32	20.16	....	23.60	10.48	7.76
20	....	18.32	20.16	21.00	23.60	10.48	7.76
21	....	18.32	20.16	21.00	23.60	10.48	7.76
22	7.40	18.32	24.00	21.00	23.60	9.08	7.76
23	8.76	18.32	24.00	21.00	23.60	9.08	7.76
24	9.00	18.32	24.00	21.00	23.60	9.08	7.76
25	9.36	18.32	26.08	21.88	21.60	9.08	7.76
26	9.36	20.12	24.00	22.80	21.60	9.08	....
27	8.76	22.08	18.32	....	21.60	9.08	....
28	5.92	22.08	12.32	2.32	21.60	9.08	....
29	7.44	22.08	12.32	2.32	21.60	9.08	....
30	9.16	22.08	19.40	5.44	21.60	9.08	....
31	....	24.00	....	....	21.60	....	....
Total	75.16	515.28	602.92	511.52	664.60	375.00	149.84

Use of water from Rutledge lateral.

[520 acres irrigated; 15 users; distribution partly by rotation, partly by continuous flow.]

Day.	April.	May.	June.	July.	August.	September.	October.
	Acre-feet.	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*
1	....	14.00	12.56	14.28	10.88	12.56	5.04
2	....	14.00	12.56	17.08	14.28	14.28	9.32
3	....	14.00	....	16.16	12.56	14.28	9.32
4	....	10.40	12.56	15.20	12.56	12.56	5.04
5	....	7.84	15.20	15.20	13.44	12.56	5.04
6	....	5.76	13.44	15.20	15.20	10.88	3.88
7	....	5.76	13.44	15.20	15.20	14.28	5.04
8	....	3.84	13.44	16.16	15.20	15.20	7.76
9	....	7.84	14.28	15.20	15.20	15.20	5.04
10	....	7.84	14.28	15.20	15.20	....	2.76
11	....	5.32	15.20	14.28	15.20	....	2.76
12	....	5.40	15.20	13.44	14.28	12.56	2.76
13	....	15.20	14.28	13.44	14.28	14.28	2.76
14	....	15.20	14.28	13.44	14.28	14.28	2.76
15	....	18.24	13.44	12.56	14.28	14.28	2.76
16	....	17.28	13.44	15.36	14.28	12.56	2.76
17	....	17.00	14.28	15.36	14.28	12.56	1.84
18	....	16.80	13.44	....	14.28	12.56	1.84
19	....	14.84	16.12	14.28	14.28	12.56	1.84
20	....	14.84	16.12	14.28	14.28	12.56	1.84
21	....	14.84	15.20	14.28	15.20	10.88	1.84
22	....	14.84	15.20	14.28	15.80	7.76	2.76
23	....	15.60	15.20	....	15.80	7.76	2.76
24	5.92	12.56	15.20	10.88	15.80	....	3.88
25	5.80	12.56	14.28	14.28	13.44	....	3.88
26	5.80	12.56	12.56	14.28	14.28	....	....
27	7.92	12.56	11.68	12.56	13.44	....	....
28	7.92	12.56	10.84	....	12.56	5.04	....
29	8.72	15.20	11.68	9.32	12.56	5.04	....
30	8.80	11.68	14.28	1.88	12.56	5.04	....
31	....	12.56	....	6.52	12.56	....	....
Total	50.88	378.92	403.68	379.60	437.44	281.52	97.28

Use of water from Tuttle lateral.

[582 acres irrigated; 18 users; distribution partly by rotation, partly by continuous flow.]

Day.	April.	May.	June.	July.	August.	September.	October.
	Acre-feet.	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*
1	....	16.12	20.00	18.00	24.12	16.12	10.84
2	....	21.00	20.00	18.00	23.08	17.04	10.84
3	....	21.00	20.00	16.16	23.08	16.12	10.84
4	....	21.96	20.00	14.28	23.08	16.12	10.84
5	....	14.28	20.00	16.16	23.08	16.12	10.84
6	....	18.00	20.00	16.16	23.08	16.12	9.32
7	....	18.00	19.00	20.00	23.08	14.28	9.32
8	....	....	14.44	16.16	23.08	14.28	9.32
9	....	12.56	10.84	14.28	23.08	21.96	9.32
10	....	12.56	20.00	14.28	23.08	21.96	7.76
11	....	21.96	20.00	8.52	23.08	21.96	7.76
12	....	15.20	20.00	22.20	23.08	21.96	7.76
13	....	15.20	20.00	22.20	23.08	21.96	7.76
14	....	18.00	20.00	22.20	23.08	21.96	7.76
15	....	17.04	21.00	22.20	22.00	21.96	7.76
16	....	18.00	21.00	22.20	22.00	21.96	7.76
17	....	12.56	21.96	22.20	22.00	21.96	7.76
18	....	12.56	21.96	22.20	22.00	21.00	7.76
19	....	12.56	21.96	....	22.00	21.96	7.76
20	....	12.56	20.00	....	22.00	21.96	7.76
21	....	12.56	20.00	20.00	22.00	21.96	7.76
22	....	18.00	21.08	22.20	23.08	21.96	7.76
23	....	18.00	21.96	21.00	23.08	18.00	7.76
24	....	19.00	20.00	21.00	23.08	18.00	7.76
25	14.00	19.00	21.96	23.04	23.08	18.00	7.76
26	16.00	19.00	20.00	20.00	22.00	15.20	....
27	18.00	19.00	20.00	20.00	17.08	15.20	....
28	18.00	15.96	20.00	6.52	17.08	15.20	....
29	18.00	21.00	17.04	....	17.08	14.28	....
30	20.00	21.00	17.04	22.20	17.08	14.28	....
31	....	19.96	....	22.20	17.08	....	....
Total	104.00	513.60	591.24	525.56	677.88	560.84	215.64

Use of water from Pollard lateral.

[199 acres irrigated; 8 users; distribution partly by rotation, partly by continuous flow.]

Day.	April.	May.	June.	July.	August.	September.
	Acre-feet.	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*
1	....	1.56	3.24	5.44	7.12	5.44
2	....	1.56	4.20	5.44	7.12	5.44
3	....	1.56	....	4.84	7.12	5.44
4	....	1.56	5.96	4.84	5.96	5.44
5	....	1.56	5.96	4.84	5.96	5.44
6	....	1.56	5.96	4.84	5.96	5.44
7	....	1.56	6.48	4.84	5.96	5.44
8	....	1.56	5.44	4.84	5.44	5.44
9	....	4.80	5.44	4.84	5.44	5.44
10	....	5.96	5.44	....	5.44	4.20
11	....	6.48	5.44	5.96	5.44	4.20
12	....	6.48	5.44	5.96	5.44	4.20
13	....	3.24	4.80	5.44	5.44	4.20
14	....	3.24	4.20	6.48	5.44	4.20
15	....	3.24	7.12	6.48	5.44	4.20
16	....	3.24	7.12	6.48	5.44	4.20
17	....	3.24	7.12	6.48	5.44	4.20
18	....	3.24	6.20	6.48	5.44	4.20
19	3.28	3.24	5.96	6.48	5.44	4.20
20	3.32	3.24	5.96	6.48	5.44	4.20
21	3.36	3.24	5.96	6.48	5.44	4.20
22	3.28	3.24	5.96	7.12	5.44	4.20
23	3.28	6.48	5.96	....	5.44	4.20
24	3.28	6.48	5.96	6.48	5.44	4.20
25	3.28	5.96	5.96	6.48	5.44	4.20
26	3.36	5.96	5.44	6.48	5.44	....
27	5.40	3.24	5.44	....	4.80	....
28	5.40	3.24	4.80	....	5.40	....
29	6.40	3.24	4.80	....	5.44	....
30	6.40	3.72	4.20	....	4.80	....
31	....	3.72	....	4.20	4.80	....
Total	50.04	110.64	161.96	144.72	173.80	116.16

Use of water from the Clark lateral.

[257 acres irrigated; 4 users; distribution by continuous flow.]

Day.	April.	May.	June.	July.	August.	September.	October.
	Acre-feet.	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*
1	....	5.04	7.32	7.68	3.12	7.68	7.68
2	....	5.04	7.00	7.68	7.32	7.68	7.68
3	....	5.04	7.36	7.68	7.00	7.68	7.68
4	....	5.04	7.68	....	7.00	8.04	7.68
5	....	5.04	7.84	7.00	7.00	8.04	6.00
6	....	5.04	7.00	7.68	7.00	8.04	6.00
7	....	4.76	7.84	....	7.68	8.04	6.32
8	....	5.04	3.20	3.64	6.68	7.00	6.32
9	....	5.04	7.84	8.04	6.68	7.68	6.00
10	....	5.04	8.36	8.04	7.32	7.68	6.00
11	....	5.04	8.04	7.32	7.00	7.68	5.36
12	....	5.04	7.32	7.32	7.00	....	5.36
13	....	5.04	7.32	7.00	7.32	7.32	5.36
14	....	7.84	7.32	7.00	7.00	7.32	5.36
15	....	7.84	7.68	6.68	7.00	7.68	6.00
16	....	7.84	7.32	7.36	7.32	7.32	6.00
17	....	7.44	7.36	....	7.32	7.68	6.00
18	....	7.84	6.64	8.76	7.32	7.32	6.00
19	....	7.84	7.68	8.76	7.32	....	6.00
20	....	7.84	7.12	6.64	7.32	7.68	6.00
21	....	7.84	7.12	7.00	7.00	7.68	6.00
22	....	8.04	7.32	7.32	7.00	7.32	6.00
23	....	7.84	7.32	7.32	7.32	7.32	6.00
24	....	7.68	7.68	6.00	7.32	6.68	6.00
25	....	7.44	7.68	4.76	7.00	7.32	....
26	1.52	7.44	8.04	4.20	7.32	7.32	....
27	1.60	8.04	8.04	4.76	7.32	7.68	....
28	1.68	7.84	7.32	4.20	7.68	7.68	....
29	1.76	8.04	7.68	3.12	7.68	7.68	....
30	1.72	8.04	7.32	3.12	7.68	7.68	....
31	....	7.84	....	....	7.68	....	....
Total	8.28	205.80	220.76	176.08	219.72	211.92	148.80

Use of water from Perkins lateral.

[187 acres irrigated; 10 users; distribution by continuous flow.]

Day.	April.	May.	June.	July.	August.	September.	October.
	Acre-feet.	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*
1	....	6.00	5.16	5.16	5.20	4.76	2.88
2	....	6.00	5.16	5.16	5.20	4.76	2.88
3	....	4.92	3.84	5.16	5.20	4.76	....
4	....	4.92	5.16	5.16	5.20	4.76	....
5	....	4.88	5.68	5.16	5.20	4.76	....
6	....	6.44	5.16	5.16	5.20	4.76	....
7	....	6.44	6.72	....	5.20	4.76	....
8	....	6.44	4.76	5.16	5.20	4.76	....
9	....	6.44	6.20	3.36	5.20	4.76	....
10	....	6.44	5.16	3.36	5.20	4.76	2.52
11	....	6.44	5.16	5.16	5.20	4.76	2.52
12	....	6.44	5.16	5.16	5.20	4.76	2.52
13	....	6.44	5.16	5.16	5.20	4.76	2.52
14	....	6.44	5.68	5.16	5.20	4.76	2.52
15	....	6.44	5.68	5.16	5.20	4.76	2.52
16	....	6.44	5.16	5.16	5.20	4.76	3.24
17	....	7.92	5.16	5.16	5.20	4.76	3.24
18	....	7.92	5.16	5.16	5.20	4.76	3.24
19	....	7.92	5.16	5.16	5.20	4.76	3.24
20	....	7.92	6.72	5.16	5.20	4.76	3.24
21	....	5.16	6.72	5.16	5.20	4.76	3.24
22	....	5.16	4.76	5.16	5.20	....	2.88
23	....	5.68	4.76	5.16	5.20	....	2.88
24	....	5.16	4.76	5.16	5.20	....	2.88
25	4.00	5.16	4.76	....	5.20	3.36	2.88
26	4.00	5.16	4.76	5.16	5.20	3.36	....
27	5.00	5.68	4.76	3.36	5.20	3.36	....
28	5.00	5.16	4.76	2.60	5.20	3.36	....
29	6.00	5.68	4.76	2.60	5.20	3.36	....
30	6.00	5.68	4.76	1.74	5.20	3.36	....
31	....	5.68	....	....	5.20	....	....
Total	30.00	188.60	156.76	130.54	161.20	120.12	51.84

Use of water from the Brose lateral.

[257 acres irrigated, 8 users; distribution by continuous flow.]

Day.	April.	May.	June.	July.	August.	September.	October.
	Acre-feet.	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*
1	....	8.40	9.04	8.44	8.40	8.44	7.80
2	....	7.12	8.40	8.68	8.40	8.44	7.80
3	....	9.04	8.40	8.44	8.40	8.44	8.40
4	....	11.48	8.40	8.44	8.40	8.44	7.80
5	....	10.48	8.40	8.68	8.40	8.44	7.80
6	....	11.48	9.80	8.44	8.40	8.44	7.80
7	....	11.48	9.04	8.44	8.40	8.44	7.80
8	....	11.48	8.40	8.44	8.40	8.44	6.48
9	....	10.48	9.04	5.96	8.40	8.44	6.48
10	....	8.00	9.76	5.44	8.40	8.44	6.48
11	....	8.40	10.00	8.44	8.60	8.44	6.48
12	....	9.04	9.04	8.44	8.60	8.44	5.96
13	....	9.04	9.76	8.68	8.60	8.44	5.96
14	....	9.04	9.76	8.68	8.60	8.44	6.48
15	....	11.20	9.76	8.68	9.04	8.44	6.48
16	....	11.48	11.80	8.44	8.40	8.44	6.48
17	....	11.20	13.44	5.44	9.04	7.80	6.48
18	....	9.40	8.40	8.68	9.04	7.80	6.48
19	....	9.40	8.60	8.68	9.04	7.80	7.80
20	....	8.80	8.60	8.68	9.04	7.80	7.80
21	....	8.72	8.60	8.68	8.40	7.80	7.52
22	....	8.72	8.60	8.68	8.40	7.80	7.52
23	....	8.72	8.60	8.40	8.40	7.80	7.52
24	....	8.72	8.60	8.68	8.40	7.80	7.52
25	....	7.12	8.40	9.04	8.60	7.80	7.52
26	....	8.08	8.60	9.04	8.40	8.80	....
27	....	9.04	8.60	8.44	8.40	7.80	....
28	3.72	9.04	8.40	8.44	8.40	7.80	....
29	8.40	9.04	8.40	8.44	8.60	7.80	....
30	9.04	8.40	9.04	8.44	8.40	7.80	....
31	....	11.88	....	....	8.40	....	....
Total	21.16	293.92	273.68	248.52	264.80	244.24	178.64

Use of water from Rust lateral.

[760 acres irrigated, 21 users; distribution by continuous flow.]

Day.	April.	May.	June.	July.	August.	September.	October.
	Acre-feet.	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*
1	....	26.80	28.48	33.08	28.48	30.32	24.12
2	....	27.36	28.48	29.60	29.04	30.32	25.20
3	....	27.36	19.64	29.60	28.48	28.48	25.20
4	....	27.36	28.48	29.60	29.04	28.48	24.12
5	....	28.48	31.92	30.76	31.92	28.48	24.12
6	....	31.32	27.84	38.08	28.48	30.32	24.12
7	....	27.36	28.48	28.48	28.48	30.32	24.12
8	....	28.48	15.64	29.60	28.48	27.36	24.12
9	....	26.80	20.80	4.48	29.04	33.08	23.04
10	....	26.80	28.48	5.04	28.48	31.92	25.20
11	....	27.36	28.48	5.76	28.48	28.48	25.20
12	....	26.80	29.60	29.60	29.04	27.36	25.20
13	....	27.36	29.60	28.08	29.04	30.32	24.12
14	....	27.36	29.60	29.76	29.60	28.48	24.12
15	....	27.36	27.36	29.60	28.48	26.24	24.12
16	....	28.48	27.84	29.60	28.48	28.48	24.12
17	....	28.48	28.48	28.08	33.08	26.24	24.12
18	....	28.48	28.48	5.04	33.08	25.16	25.20
19	....	28.48	28.48	28.08	28.48	28.48	24.12
20	2.76	28.48	29.60	29.60	28.48	26.24	24.12
21	5.04	28.48	31.92	28.08	28.48	25.16	24.12
22	5.04	28.48	27.36	28.08	28.48	25.16	24.12
23	10.88	28.48	28.48	29.60	28.48	25.16	24.12
24	12.56	28.48	27.84	29.60	29.60	24.12	24.12
25	11.72	28.48	27.84	29.60	29.04	25.16	24.12
26	11.72	28.48	28.48	28.48	30.24	24.12	....
27	19.00	28.48	27.84	3.92	29.60	24.12	....
28	27.36	28.48	28.48	5.04	29.04	25.16	....
29	28.80	27.88	30.24	5.76	30.72	25.16	....
30	27.84	28.48	32.40	11.72	35.44	25.16	....
31	....	27.88	....	19.00	28.48	....	....
Total	162.72	868.84	836.64	720.40	913.76	823.04	608.40

It will be observed from an examination of the table which follows, and which is arranged to give a comparison of these results, that those who were endeavoring to economize used a greater percentage of their season's supply during the early part of the season, this amount being 15 per cent during April, as against 3 per cent in the case of those who allowed their water to flow continuously. There was more new land cultivated in this case, which might account for the difference.

Amount of water used under different systems of distribution from the Ridenbaugh Canal system, Boise Valley, Idaho.

ROTATION.

Name of lateral.	April.	May.	June.	July.	August.	September.	October.	Total.	Users.	Area.	Average depth.
Crawford lateral:	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*		*Acres.*	*Feet.*
Blackstock, G	4.24	29.28	32.80	29.52	33.00	10.00	13.08	151.92	1	40	3.80
McNeilly	9.37	57.52	36.00	65.60	46.00	18.00	14.76	247.25	1	65	3.80
Parks	3.33	24.96	11.20	25.52	27.20	8.00	6.72	106.93	1	30	3.56
Fraser	3.53	20.72	14.00	15.76	6.80	11.60	....	72.41	1	30	2.41
Blackstock, R. L	3.53	2.00	12.00	22.96	23.20	....	....	63.69	1	25	2.55
Jones	2.12	29.00	12.00	18.04	9.72	5.00	8.56	84.44	1	25	3.38
Total	26.12	163.48	118.00	177.40	145.92	52.60	43.12	726.64	6	215	3.88
Huntington lateral	2.40	68.24	83.75	84.50	99.80	57.44	....	396.13	6	130	3.04
Creeson lateral	756.00	796.72	749.92	852.56	654.28	329.84	....	4,139.32	24	924	4.48
Total	784.52	1,028.44	951.67	1,114.46	900.00	439.88	43.12	5,262.09	36	1,269	4.14
Percentage	15	20	18	21	17	8	1	100	....	....	....

ROTATION AND CONTINUOUS FLOW.

Name of lateral.	April.	May.	June.	July.	August.	September.	October.	Total.	Users.	Area.	Average depth.
Hunter lateral	75.16	515.28	602.92	511.52	664.60	375.00	149.84	2,894.32	20	683	4.24
Rutledge lateral	50.88	378.92	403.68	379.60	437.44	281.52	97.28	2,029.32	15	520	3.90
Tuttle lateral	104.00	513.60	591.24	525.56	677.88	560.84	215.64	3,188.76	18	582	5.47
Pollard lateral	50.04	110.64	161.96	144.72	173.80	116.16	....	757.32	8	199	3.81
Total	280.08	1,518.44	1,759.80	1,561.40	1,953.72	1,333.52	462.76	8,869.72	61	1,984	4.47
Percentage	3	17	20	18	22	15	5	100	....	....	....

CONTINUOUS FLOW.

Name of lateral.	April.	May.	June.	July.	August.	September.	October.	Total.	Users.	Area.	Average depth.
Clark lateral	8.28	205.80	220.76	176.08	219.72	211.92	148.80	1,191.36	4	257	4.64
Perkins lateral	30.00	188.60	156.76	130.54	161.20	120.12	51.84	839.06	10	187	4.49
Brose lateral	21.16	293.92	273.68	248.52	264.80	244.24	178.64	1,524.96	8	257	5.93
Rust lateral	162.72	868.84	836.64	720.40	913.76	823.04	608.40	4,933.80	21	760	6.49
Total	222.16	1,557.16	1,487.84	1,275.54	1,559.48	1,399.32	987.68	8,489.18	43	1,461	5.81
Percentage	3	18	17	15	19	17	11	100	....	....	....

The foregoing is the record of the irrigation of 4,714 acres of land under this system, upon which there was used during the season 22,620.99 acre-feet, making an average depth of 4.80 feet. The total area irrigated by the "Ridenbaugh" system during 1901 was about 22,500 acres, which required an average depth of almost exactly 5 feet. About 20 per cent of the land referred to in these records was in grain, about 65 per cent in meadow, the remaining 15 per cent being in orchard and garden.

Referring to the order of the county commissioners from which the Boise City Irrigation and Land Company appealed, it might be well to state that there was no desire on the part of the company to increase its revenue at the expense of the irrigator—that is, by increasing the cost per acre of irrigation. What it was most desirous of doing was to induce economy in the use of water, and establish a system of administration which would be in accord with conditions surrounding the water supply, in anticipation of the extensive developments which the company hopes soon to be able to make in its canal system.

The company could increase its delivery of water from the beginning of the season until the end of June or middle of July by enlarging its canal; but no matter what the capacity of the canal might be the July and August flow would never be any more than it is at present, or than it has been for the past three seasons, for the reason that this canal is now diverting, during the low stage of the river, about all the water it is entitled to. Therefore it should be apparent that, even after their works shall have been enlarged to four or five times their present capacity, the company can not deliver water according to the plan of the county commissioners unless they and the irrigators are willing to limit their operations to the utilization of the probable amount of water which the canal will be entitled to divert from the Boise River during its low stage of July and August. This would be all the water the canal company could contract to deliver "continuously throughout the irrigating season."

Although the new system of distribution proposed by the company had the support and cooperation of only about one-half the irrigators—the other half, many of them at least, allowing the water to flow without cessation during every day of the irrigating season—the area under cultivation was increased from about 19,000 acres to 22,500 in one season. This increase was not due to any increase in the capacity of the canal, but was due solely to a more methodical handling of the water supply by the water masters and part of the irrigators. Now that the issue is before the court, both the company and the irrigators are very anxious for a settlement of the differences. The principal issue raised by the company in the complaint which it filed in the United States court relates to the rate sought to be fixed by the county commissioners, it being claimed that the rate sought to be charged would

result in the practical confiscation of the property of the complainant, or the taking of its property without due process of law. This allegation would without doubt be true unless it could be demonstrated that it would be practicable to deliver the June discharge of the Boise River to the irrigators during the month of August. The question of the proper basis for rates and the distribution of the available water supply will undoubtedly be entered into later.

These questions are really of greater importance than is the rate itself. The rate can be changed and adjusted from time to time, like charges for any other service, without causing any great inconvenience to a community. The method of distributing the water supply should be based upon sound principles. It should take into full account the natural conditions which relate to this case and which can not be changed. The plan finally decided upon should have for its object the greatest good to the greatest number. This object will be attained when provision is made so that it will be profitable to divert and use the waters at all stages of the river's flow—some equitable system which takes into account the rights of the early user as well as the condition of that large class of settlers of the future whose rights will of necessity expire with the subsidence of the flood discharge of the river. Under normal conditions, or until the flood waters are conserved by storage, a small number of settlers will be entitled to receive water during the entire irrigating season, while a much larger number will be able to get it only until the first or the middle of July. This is because the water will not be available for use after that date. Should these two classes of users be obliged to pay the same amounts for the delivery of their water, in the one case throughout the entire season, in the other until about the middle of the irrigating season? This is the real question which the court must finally decide in this case.

The controversies and agitations which have grown out of the vexed questions in this case have not been without their good results. As a general proposition, nearly every irrigator in the valley believes that more economical methods for the distribution of the waters of the Boise River should be adopted, but as a rule they are not ready to make a change until obliged to.

REGULATIONS FOR THE DISTRIBUTION OF WATER IN THE PIONEER IRRIGATION DISTRICT.

The time to give careful consideration to this feature of the question is in the beginning, when the irrigation system is first planned. The action of the Pioneer Irrigation District, an organization whose territory lies contiguous to the lands under the Ridenbaugh Canal, is in line with this idea. The directors of this organization, realizing the troubles which have so frequently resulted from the neglect to

carefully consider these matters, have drafted a code of rules and regulations for the administration of the canal system belonging to the district. The regulations relating to the distribution of water are of interest for the reason that they provide for the use of water in turn.

The user, however, is not to be the judge of the head to be applied, but each irrigator shall take not less than a full irrigating stream (2 cubic feet per second) whenever it comes his turn to irrigate. This plan will not only greatly simplify the work of distributing the water, but will facilitate irrigation itself. There will always be several such irrigating streams flowing in each main lateral. It will only be necessary to divide this head into the large "streams," thus rendering the exact measurement of the water unnecessary. Each irrigator will then be allotted a certain time during which to use a stream, the time varying with the area of the tract to be irrigated. When tracts are very small or the surface of the field so sloping that a smaller stream could be more advantageously applied, special arrangements can be made through the water master for the delivery of the same. These rules also contain many wise provisions in relation to the maintenance and care of laterals which should be of great interest to the irrigators. That portion of the rules relating to the duties of water masters and the general obligations of irrigators follows:

ARTICLE VI.—WATER MASTERS.

SECTION 1. It shall be the duty of every water master to supervise the distribution of water to authorized users within his district. He shall arrange a schedule of turns and give to each person a card indicating the time when the water will be turned into his lateral and the length of time which he shall be entitled to it. And it shall be the duty of the water master to distribute water according to said schedule.

SEC. 2. Two second-feet shall constitute an irrigation stream and form the basis of all calculations of quantity of water used. Each user shall be charged according to the time he shall use an irrigation stream. Any person desiring it may use at the same time more than one irrigation stream and be charged accordingly, but no one may use a lesser amount unless agreeable arrangements can be made with parties receiving water from the same lateral, or with the consent of all such parties, or when the use of a lesser amount will not operate to the injury of anyone else.

SEC. 3. When all users deriving water from the same main lateral agree to attend to their own distribution and make proper application to the board, according to such terms as the board of directors may provide, the employment of a water master for that lateral may, in the discretion of the board of directors, be dispensed with and the water rate correspondingly reduced.

SEC. 4. It shall be the duty of the water master to keep all laterals within his district in proper condition, and to that end he may at any time call out the users of water in his district to clean out and repair such laterals as may require cleaning or repairing; and he shall apportion the work among the several users according to the amount of water used by each. If any such user shall fail or neglect to come out when called by the water master, then the water master may employ some one else at the expense of the person so failing, refusing, or neglecting, and the water master shall refuse to serve such person with water until he has paid all expenses incurred by the said failure or neglect.

SEC. 5. If any water master shall refuse to give water to any authorized user, when said user is entitled to it under his schedule, or if any water master shall fail to shut water off from any authorized user when his time has expired, and it shall appear that such failure of duty on the part of the water master was caused by neglect, carelessness, prejudice, or partiality, then such water master shall be subject to instant dismissal, and shall be liable on his bond for any damages incurred.

SEC. 6. It shall be the duty of the water master to keep a book in which he must enter the name of every user of water within his division, together with a description of his land, the date when said user began to take water, the number of hours allotted to each turn, the hour when turn begins, the hour of ending, day of week and month. Said book shall at all convenient times be subject to public examination, and any water master refusing to exhibit the same, or making therein any false or misleading entry, shall be liable to instant removal, and also liable on his bond for any damages caused through such refusal or improper entry.

ARTICLE VII.—GENERAL PROVISIONS.

SECTION 1. Any person aggrieved by any action of the water master of his district shall make complaint in writing to the board of directors of the district within five days from the time of the commission of the alleged wrong, and said complaint must be filed with the secretary of the board at his office in Caldwell. Whereupon it shall be the duty of the secretary to notify the president of the board of directors and the water master complained of, that such complaint has been filed, and the president must, within five days from the date of such notification, unless said complaint be previously withdrawn, fix a day for the hearing of said complaint, and he must call a meeting of the board of directors on the date of such hearing, and all parties concerned must appear before the board of directors, with such witnesses as they may have, on the day set. The directors must make a thorough investigation and render such a decision as in their judgment seems proper. The hearing must be postponed from day to day, but not exceeding three days in all, and at the close thereof, and within twenty-four hours, the directors must render their decision.

SEC. 2. Any person of the district who may take water without the consent of the water master, or who shall in any way tamper with head gates or laterals, shall be fined in any sum not less than $10 nor more than $50. And it shall be the duty of every water master to promptly make complaint in writing to the board of directors in the manner and form prescribed in section 1 of this article, of all such offenses, and after the fine has been imposed he shall withhold the water from said member until the fine is paid. Any water master failing to promptly report as herein required shall be subject to instant dismissal and liable on his bond for any damage incurred through his neglect or violation of duty.

SEC. 3. Every member of the district using water shall be personally responsible for the gate, dam, or flume that leads water to his lands. It shall be good evidence against him before the board of directors if any water passes through his gate, dam, or flume without the consent of the water master, and unless he can show to the satisfaction of the board that he was in nowise responsible for the passage of said water, he shall be dealt with according to section 2 of this article.

SEC. 4. Every user of water in the district and every one contemplating the use of water should file with the secretary of the board of directors in January of each year a statement of the amount of land he or she intends to irrigate during the ensuing season, together with such other information as will enable the board of directors to approximately ascertain the amount of water that will be needed in the whole district and the character and extent of improvements and enlargements necessary.

The following is from a letter from Mr. R. H. Davis, of Caldwell, secretary of the district, to the State engineer, and should be of inter-

est, as it explains very clearly the provision in the above rules regarding the use of water in turn:

Regarding the provisions contained in article 6, section 2 of the rules, I would say that it is designed to meet a peculiar condition which has grown out of the perpetual flow system. About two-thirds of the water users insist upon having a small stream flowing onto their premises constantly. If granted, a large amount of water would be frittered away and comparatively few would ever, except in flood time, have enough water at one time for economical irrigation. The result would be a modified and complicated perpetual flow system.

If the rotary system is correct, and of that I have not the slightest doubt, it must be applied strictly, and farmers must adapt themselves to it. I believe that ultimately irrigators will come to regard their water rights in the sense of shares of water, and lose sight of the acreage which was originally the basis of the shares for distribution. Then a water share will represent a certain amount of water for a given number of hours, and experience will indicate about how much land the share will irrigate.

A water share in any locality where the source of supply varies is necessarily a rather indefinite thing, but after a few years' experience people come to know about its average value. To me the establishing of a rotary system essentially involves the idea of an "irrigation stream," or minimum standard. How rotary distribution could be reduced to practice where every user could take as few or as many units, or fractions of units, rather as convenience might suggest, is incomprehensible to me. Suppose you have twenty users on one lateral, the first man demanding 40 inches for forty-eight hours, the second 10 inches for fifteen hours, the third 35 inches for sixty hours, the fourth 100 inches for twenty-four hours, etc., how could such a complicated arrangement be adjusted?

By properly constructing laterals and preparing land, 2 second-feet can be used on 5 acres as well as on 500. I know this to be true, for I have used 150 miner's inches on 4 acres; and on that ground I raised 1 acre of alfalfa, 2 acres of oats, one-half acre of orchard, and one-half acre of potatoes, corn, and garden truck. The same thing can be seen all over eastern Idaho to-day.

REGULATIONS FOR THE DELIVERY OF WATER FROM THE WESTON CREEK RESERVOIRS.

Mr. Davis refers in the foregoing letter to the practice of the irrigators in the southeastern part of Idaho. This portion of the State was settled by Mormons who inaugurated many sensible irrigation customs, which in most cases were based upon necessity. The organization of the Weston Reservoir Company, of Weston, Oneida County, furnishes an example of the plan referred to by Mr. Davis. This company owns two small reservoirs, which store a part of the flood waters of Weston Creek. A share in this company costs $10, which entitles the owner to the use of an irrigating stream for one hour every fifteenth day, or a $240 interest would entitle the holder to the use of the stream one day in fifteen. The stream varies in size from two-fifths to one cubic foot per second, depending upon the flow of the creek. In localities where the water supply is meager and the right to it is held as the common property of the community some such regulation as this is usually adopted as a basis for its distribution. It

is usually when works have been built by a person or company for the purpose of delivering the water to the landowners under a so-called "rental" system that troubles have arisen in this State over the distribution of the supply.

REGULATIONS FOR THE DISTRIBUTION OF WATER FROM THE MOUNTAIN HOME RESERVOIR.

The management of the Mountain Home Reservoir, in Elmore County, has furnished an example of complications of this nature. A water supply overestimated, an abundance of fine land which the people were very desirous of reclaiming, an extravagant estimate of the duty of water, and a desire to please everybody, led the early management into trouble which it has taken years to undo.

This reservoir impounds practically the entire season's supply of water for the irrigation of the lands about the town of Mountain Home. There is a practically unlimited arēa of land, but with a water supply the extent of which is known every season before a head gate is raised. Yet the company for years has been charging for the delivery of water by the acre without measurement.

The first contracts, or "perpetual water rights," entered into provided for a right to water to a depth of 1 foot over each acre of land, for which the irrigator was to pay $1.50 per acre each season. No attention was paid to this provision by either the company or the irrigator, but the irrigator was allowed all the water he asked for. These "perpetual water rights" covered about one-third of the land irrigated, the charge for delivering water to the remainder being at the rate of from $2.50 to $4 per acre, depending upon the size of the tract, all tracts smaller than 4 acres paying the latter rate. Nearly all the users kept their water flowing continuously.

The affairs of this company were reorganized during the early part of 1901, when it was realized that the success of the projects designed to extend the work of irrigation development in that vicinity depended almost solely upon the attaining of a higher duty of water under the system then in use. With a view of increasing the efficiency of the present water supply, the company decided to deliver the water to the users in large heads in turn or rotation. The irrigators did not object very seriously to the rules, but serious objections were raised against the rate which was proposed by the company—6 cents for one-fiftieth part of a cubic foot per second, or 1 inch, for each twenty-four hours.

In order to adjust all differences and inaugurate a new system harmoniously, a committee of disinterested persons was appointed by the company to confer with a committee representing the irrigators. As a result of this conference, the following rules and regulations were adopted and stipulations entered into as a basis for the operations during the irrigating season of 1902.

Rules and regulations for the delivery of water for irrigation from the Mountain Home Reservoir.

(1) The irrigating season as provided by law begins April 15 and ends November 1. The company will be prepared to distribute water for irrigation between these dates.

(2) No water will be delivered to any applicant until all charges due for the delivery of water during the previous year shall have been settled in full.

(3) Application for water shall be made on or before January 1 of each year on blanks furnished by the company.

(4) In distributing water from this reservoir system preference will be given those applications for water for land irrigated the preceding season, and a surplus of water, if any there be, will be delivered to other lands in the numerical order of the application for it.

(5) An allowance of 2 acre-feet for each acre irrigated will be the basis for delivery over the area for which applications will be allowed until such time as experience shall have demonstrated that a higher duty of water than this can be attained under this system.

(6) The unit of volume which will be used in the distribution of water to the irrigators is a "head," which will be 100 inches, or 2 cubic feet, per second; this will be divided into "half-heads" or 50 inches, "quarter-heads" or 25 inches, "tenth-heads" or 10 inches, and "twentieth-heads" or 5 inches. The unit of time in distribution will be a "twenty-four-hour run," or one day of twenty-four hours. This will be divided into a "day run" of twelve hours and a "night run" of twelve hours.

(7) Water will be delivered only in "heads" or fractions of "heads," as described in rule 6, but a "run" may be for a day or days, or any fraction of a day or night.

(8) Water will be measured to every user. The measuring device at the head of all main laterals will be put in by the company at its own expense. All measuring devices, whenever needed at the head of service or individual laterals, must be put in under the supervision of the company, but at the expense of the users. No delivery of water will be made until provision shall have been first made for its measurement. All measuring devices will indicate by inspection the amount of water passing through them. No measuring devices shall be used which do not meet with the approval of the State engineer of Idaho.

(9) Before water will be delivered to any irrigator his laterals must be cleaned out and put in good condition. Laterals will be constructed of ample capacity for the head of water which they are intended to carry. They shall be kept clear of sediment, moss, and other obstructions, and should they become damaged from any cause during the irrigating season, they shall be repaired before water will be again delivered through them.

(10) The entire lateral system will be operated under the supervision of a water master, who will be appointed by the company. It shall be his duty to measure and deliver the heads of water ordered by the irrigators and prevent waste from any cause in the application of the water delivered by him.

(11) The irrigator shall be the judge of the "head" best suited to his needs and shall be entitled to have the same delivered to his lands for such time and at such intervals as he may deem best.

(12) In ordering water the irrigator will be required to notify the water master at least two days before the water is needed, stating the fraction of a "head" required and the length of time the same will be needed. These notices shall be made out on cards furnished by the company.

(13) Where two or more irrigators take water from the same lateral, they shall, with the assistance of the water master, arrange the time of irrigation so that the head flowing in the lateral may be used in turn or rotation. This arrangement would

not, however, oblige a user to take water if he did not need it, but if for any reason he should not be ready to take it when his turn arrived, he would be obliged to wait until the next rotating period. In the irrigation of town lots, the water master will devise a system of rotation for each group of lots under a common lateral.

(14) Water will be delivered only for beneficial purposes; therefore, the wasting of water will not be allowed under any circumstances, and the company will refuse to deliver the public waters to a wasteful irrigator, no matter whether he is willing to pay for its delivery or not.

(15) The charge for the delivery of water during the irrigating season of 1902 will be according to the following schedule of rates:

Rate.

Head.	Inches.	24-hour "run."	12-hour "day run."	12-hour "night run."
One	100	$4.00	$2.25	$1.75
One-half	50	2.25	1.25	1.00
One-fourth	25	1.25	.70	.55
One-tenth	10	.60	.35	.25
One-twentieth	5	.35	.20	.15

(16) Water will be delivered to an irrigator only for such time as he may designate in his notice to the water master or during the time of his turn as arranged in each recurring period of rotation. Anyone, therefore, who takes water which he has not formally applied for or uses it out of his turn without the consent of the irrigator whose turn he takes will forfeit all right to the further use of water from this system for the remainder of the season and will also be liable for prosecution under the laws of this State.

STIPULATION SIGNED BY THE COMMITTEES.

We, the committee appointed by the Elmore County Irrigated Farms Association, hereby fix the water rate for the irrigation season of 1902 as follows:

Head.	Inches.	24-hour rate.	Day rate.	Night rate.	Acre-foot.	Acre.
One	100	$4.00	$2.25	$1.75	$1.00	$2.00
One-half	50	2.25	1.25	1.00	1.12½	2.25
One-fourth	25	1.25	.70	.55	1.25	2.50
One-tenth	10	.60	.35	.25	1.50	3.00
One-twentieth	5	.35	.20	.15	1.75	3.50

That the rules set forth by State Engineer Ross for the Elmore County Irrigated Farms Association shall govern the management and distribution of said water. Where land is not on the company's main canal or lateral, the water is to be measured at a point not exceeding one-fourth mile from where it enters the user's property, said point to be designated by the company.

Water users to pay in advance or furnish a good and sufficient guaranty for the payment of water rental to the company before the water will be turned on.

Water rental not paid for in advance must be paid for at the following periods: The first half of the annual rental to be paid on July 15, 1902; the balance to be paid on or before September 15, 1902, for water used during the irrigation season of 1902.

Water users in arrears in the payment of water rental must first pay up back rents before the water will be turned on this season.

This committee urgently requests the water users to use the greatest economy in handling said water in irrigation and avoid waste as much as possible, the consumer and company being equally benefited thereby.

It is understood and agreed that the foregoing rates apply to acreage property only for the year 1902, and in no way affect rates governing the irrigation of lots within the village of Mountain Home.

In order to secure a just and economical use of water under the irrigation system of the Elmore County Irrigated Farms Association, in Elmore County, Idaho, the said company has issued and established the above rules and will expect a careful compliance therewith, so that the company may be better able to establish rates in the future.

The rates above established are believed to be equitable and fair, but as evidence of good faith upon the part of the company, it is agreed that the water rental under the above rules and rates shall not for the year 1902 exceed the rates charged for the same area during the years 1900 and 1901.

It is further agreed and stipulated that the water users will not waste said water but will use their best efforts to economize in the use of said water at all times, and will aid the said company in bringing to justice any and all persons caught tampering with any head gate or gates or taking and using water without the knowledge and consent of the water master.

The above stipulation was signed by all the members of both committees.

The company will begin the operations of 1902 by employing the services of a competent water master and putting in a complete system of measuring weirs. Inasmuch as the plans of the company which now owns this reservoir contemplate the investment of a large amount of money for the construction of other irrigation works near this place, the importance of the cooperation of the water users can not be overestimated.

INVESTIGATIONS IN PAYETTE VALLEY.

Investigations of the use of water in the Payette Valley were made during 1901 on the farm of Mr. C. G. Goodwin, situated about 7 miles south of the town of Payette, on what is known as the "bench." The land irrigated comprises an area of 54.5 acres; 26.5 acres of which was in meadow (alfalfa), 18 acres in corn, 5 acres in orchard, and 5 acres in cantaloupes. The water used for irrigation was measured in a lateral over a trapezoidal weir, the depth being recorded on a register.

In the irrigation of the land in 1901 180.69 acre-feet of water was used. Of this amount 30.22 acre-feet, or 17 per cent, ran off the surface, leaving 150.47 acre-feet which soaked into the ground and evaporated, or an average depth of 2.76 feet over the tract irrigated.

Investigations of the use of water on this land were made in 1900. The flow was intermittent that year, owing to breaks in the main canal. Several breaks occurred this season, as will be noticed by the records. One of these occurred during the month of June, another large one occurred about the 1st of August, and one about August 25. As a result of the last two breaks, the ground became very dry and Mr. Goodwin's crops suffered from lack of water. He tried to soak the ground up in the interval between them by using a larger head of water, nearly twice the usual head.

The amount of water used each day is shown by the following table:

The amount of water used in the irrigation of the farm of C. G. Goodwin, Payette, Idaho.

Day.	April.	May.	June.	July.	August.
	Acre-feet.	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*
1			2.10	2.01	
2		2.23	2.00	2.27	
3		.85	1.93	2.30	
4		1.81	1.91	2.36	
5		1.11	1.90	2.45	
6		1.98	1.96	2.73	
7		2.11	1.00	2.48	
8		.88	1.06	2.48	
9			1.17	2.45	
10			.60	2.43	
11		.69		2.42	
12		1.65		2.45	
13		1.82		2.44	
14		1.28		2.43	
15		1.32		2.42	
16		1.32		2.37	0.51
17		1.51		2.40	2.48
18		.96		2.40	2.30
19			.62	2.38	3.40
20			2.54	2.37	3.75
21			2.55	2.35	4.35
22			4.08	2.32	4.28
23		2.70	2.94	2.09	4.28
24		1.93	2.86	1.84	4.10
25		2.29	2.80	1.70	
26		1.65	2.70	1.45	
27		1.27	2.07	1.14	
28	1.54	.35	1.57	2.52	
29	2.22		4.48	1.70	
30	2.24	.12	1.75		
31		1.67			
Total	6.00	33.50	46.59	65.15	29.45

The duty of water in this case is shown by the following table:

Duty of water on farm of C. G. Goodwin, 1901.

Area irrigated	acres	54.5
Water used	acre-feet	180.69
Depth of water used in irrigation	feet	3.31
Water wasted	foot	.55
Average depth used	feet	2.76

The average depth used, 2.76 feet, is slightly more than was used in 1900, 2.58 feet, but it is doubtful if enough water was received during either this or last season, certainly not as much as Mr. Goodwin would have applied had the supply in the main canal been constant.

MONTANA.

IRRIGATION INVESTIGATIONS IN MONTANA, 1901.

By SAMUEL FORTIER,

Director and Irrigation Engineer, Montana Agricultural Experiment Station.

THE DUTY OF WATER IN THE GALLATIN VALLEY.

During the summer of 1901 the writer was ably assisted by H. B. Waters, W. B. Freeman, and F. L. Tavenner, students in civil engineering. The investigations in the Gallatin Valley were, for the most part, a continuation of the work of former years. The results of the past season comprise the third of a continuous series. In planning the experiments to be conducted in 1899 the main purpose kept in mind was to determine the quantities of water used by the farmers in irrigating the staple crops under usual conditions. It was impossible, with the limited means at our disposal, to make a continuous measurement of every ditch and of every irrigated farm. Only a few could be so measured. In selecting these, care and good judgment were exercised in having them represent average conditions.

Another factor which had to be considered was the loss in conveyance. No two ditches have the same efficiency. Some, by reason of their length, the character of the material, etc., lose a large percentage of the volume which passes their head gates. In measuring the quantity diverted by a ditch, without determining the loss in conveyance, the duty of water is not known, and the pertinent question, "How much water does it require to irrigate an acre of land?" is not answered for any particular case. It was therefore deemed necessary to eliminate from most of the experiments the problem of loss in conveyance by selecting representative fields on which crops were growing and measuring the water as it entered each field, as well as the land irrigated. These comprised the field experiments.

Middle Creek Canal was selected as a type of the cooperative canal. A rating flume with gauge and water register was inserted in the channel a few hundred feet below the head gate and continuous measurements made of the flow. The loss due to seepage, evaporation, and leakage was obtained by measuring each lateral near its head. No surveys

were made of the areas of each farm irrigated, but each farmer taking water from the canal was interviewed, and a close estimate made of the irrigated portion of his farm. Knowing the total area and the extent of waste land, as well as the size of each field, by seeder measurements or otherwise, it was possible to obtain fairly accurate results.

The investigations which were begun in the Gallatin Valley in 1899 have been continued with few changes during three consecutive years. The report for the season of 1899 appeared in Bulletin No. 86, the report for the season of 1900 in Bulletin No. 104 of the Office of Experiment Stations, United States Department of Agriculture, and the following tables contain the results of experiments made in 1901.

Until recent years the farmers of Gallatin County raised chiefly grain. In 1889 there were in round numbers 22,000 acres in cereals and less than 250 acres in alfalfa. This primitive method of farming is a severe test on soil fertility, and had it not been for the wonderful productiveness of this old lake basin the one-crop system would have been sooner abandoned. During three decades about the only rotation practiced by the farmers in this valley was one or two years of grain crops followed by a season of rest or summer fallow. The summer fallow added nothing to the plant food in the soil other than that contained in the weeds that were plowed under. It merely rendered more available some of the desirable ingredients. The largest capital is in time exhausted when there are no receipts to lessen the expenditures, and no soil, however fertile, can long withstand the effects of continuous grain cropping alternating with periods of rest.

The Montana Experiment Station was one of the first to raise a warning cry against the summer-fallow system. By means of experiments, press contributions, and bulletins it has striven to show that summer fallowing is not necessary on irrigated farms, that larger yields can be secured when the grain crops follow some leguminous crops, such as clover or alfalfa, and that the soil is not impoverished by such a system of cropping.

In advocating a change the station was aided by the more intelligent and progressive farmers, and through their efforts the summer-fallow system is being gradually abandoned except on the dry farms, where it would seem to be a necessity, unless alfalfa can be grown without irrigation. In 1889 the acreage summer fallowed under the Middle Creek Canal was 1,135 acres; last summer it was only 337 acres. In many other sections of Gallatin Valley there has been a similar decrease in the extent of summer-fallowed land. Clover crops which yield from 3 to 4 tons in two cuttings are being substituted. This clover when converted into mutton and beef gives a gross revenue of over $7 per ton. Such a crop is therefore as profitable as the average barley or oat crop and maintains the soil fertility.

The methods adopted in irrigating in this section of the State were described in a former report. Some of the practices common in 1899 are being modified. The earth dam is now less used, and the canvas dam is taking its place, particularly on clover and timothy meadows, and also on alfalfa fields. The raising of clover to take the place of summer fallowing has increased the acreage of that crop, and since clover is usually irrigated both earlier and later than grain crops the irrigation period has been correspondingly increased. There has also been a tendency to the use of water in large irrigation streams during stated periods instead of the small stream used continuously.

The irrigator in the Gallatin Valley and in all the older, settled portions of the State is laboring under serious difficulties. In regard to climate, soil, and water supply he has been highly favored. His chief difficulties arise from the failure on the part of the State to define and protect his rights to the use of water. The causes which now retard his progress may be briefly summarized under the following heads:

(1) The uncertainty which prevails in regard to water rights.

(2) The large number of claims that have never been adjudicated.

(3) The failure to protect the owners of decreed rights.

(4) The imperfect and unjust methods in vogue of dividing the flow of the natural streams and cooperative canals among the rightful proprietors.

The proprietor of an irrigated farm can do little to remove these difficulties. Relief can come only through the State legislature.

EXPERIMENT NO. 1.

The Montana Experiment Station farm comprises 160 acres, with about 115 acres under cultivation. It slopes to the north at from 70 to 80 feet per mile, and is traversed in the same direction by a shallow slough which can be cultivated. The soil of the most fertile portions of the farm consists of from 5 to 9 inches of vegetable loam, 15 to 20 inches of clay loam, 30 to 40 inches of clay marl, and an unknown depth of gravel and cobbles. In other portions the soil is more shallow and the river wash formed of coarse gravel and cobbles is found nearer the surface. Many of the new laterals have been laid out with an engineer's level on a uniform grade of from 0.5 to 1 inch per rod. The yields from the several clover fields tested were not kept separate but the average over all was 3.36 tons per acre for the season. The following table gives the results of this experiment:

Duty of water on clover as shown by experiment No. 1.

Items.	First irrigation.	Second irrigation.	Total.
Date of irrigation	June 5-7	July 20-22 Aug. 2-7 Aug. 11-16	
Duration of irrigation ... hours	59.5	241.25	300.75
Area irrigated ... acres	20.86	20.86	20.86
Water used ... acre-feet	7.01	12.08	19.09
Depth of water used in irrigation ... foot	.34	.58	.92
Rainfall, May 1 to September 7 ... do			.65
Total depth of water received during growth ... feet			1.57
Number of irrigators	1	1	
Average head of water used ... cubic feet per second	1.43	.61	
Average distance between field laterals ... feet			70

EXPERIMENT NO. 2.

This clover field was also located on the station farm, the average yield being 3.36 tons per acre from the two cuttings. As regards the rainfall of 8 inches, the greater amount occurred in May, which aggregated over 5 inches. This field was watered three times with the results as stated in the following table:

Duty of water on clover as shown by experiment No. 2.

Items.	First irrigation.	Second irrigation.	Third irrigation.	Total.
Date of irrigation	June 8	July 9-10	July 25-29	
Duration of irrigation ... hours	11.5	24	95	130.5
Area irrigated ... acres	5.586	5.586	5.586	5.586
Water used ... acre-feet	1.51	3.89	4.70	10.10
Depth of water used in irrigation ... feet	.27	.70	.84	1.81
Rainfall, May 1 to August 27 ... foot				.67
Total depth of water received during growth ... feet				2.48
Number of irrigators	1	1	1	
Average head of water used, cubic feet per second	1.589	1.962	.598	
Average distance between field laterals ... feet				75

EXPERIMENT NO. 3.

This experiment was conducted on the station farm and the results as given in the table which follows do not differ materially from the two preceding experiments. Barley was grown on this field in 1898, oats in 1899, and red clover in 1900 and 1901.

Duty of water on clover as shown by experiment No. 3.

Items.	First irrigation.	Second irrigation.	Total.
Date of irrigation	June 17-18	July 14-15	
Duration of irrigation ... hours	33.5	31.5	65
Area irrigated ... acres	7.13	7.13	7.13
Water used ... acre-feet	4.21	4.65	8.86
Depth of water used in irrigation ... feet	.59	.652	1.242
Rainfall, May 1 to August 23 ... foot			.62
Total depth of water received during growth ... feet			1.862
Number of irrigators	1	1	
Average head of water used ... cubic feet per second	1.52	1.79	
Average distance between field laterals ... feet			72

EXPERIMENT NO. 4.

The data pertaining to the fourth test with red clover grown on the experiment farm is included in the following table:

Duty of water on clover as shown by experiment No. 4.

Items.	First irrigation.	Second irrigation.	Third irrigation.	Total.
Date of irrigation	June 18–19	July 12–13	July 29, Aug. 6	....
Duration of irrigation ... hours	14.5	26	172.5	213
Area irrigated ... acres	6.854	6.854	6.854	6.854
Water used ... acre-feet	1.89	5.09	3.61	10.59
Depth of water used in irrigation ... feet	.276	.743	.527	1.546
Rainfall, May 1 to August 28 ... foot	....	....	....	.62
Total depth of water received during growth ... feet	....	....	....	2.166
Number of irrigators	1	1	1	....
Average head of water used, cubic feet per second	1.577	2.370	.253	....
Average distance between field laterals ... feet	....	....	....	65

EXPERIMENT NO. 5.

This field of wheat, 5.25 acres in extent and located on the experiment farm, forms the fifth experiment. The ground was seeded May 10, the crop cut September 3, and the yield was 43.2 bushels per acre.

The same field produced peas in 1898, barley in 1899, and potatoes and roots in 1900. The time of irrigation and quantities of water applied are given in the following table:

Duty of water on wheat as shown by experiment No. 5.

Items.	First irrigation.	Second irrigation.	Total.
Date of irrigation	June 27 28	July 13–14	....
Duration of irrigation ... hours	27	25.5	52.5
Area irrigated ... acres	5.244	5.244	5.244
Water used ... acre-feet	1.75	4.54	6.29
Depth of water used in irrigation ... feet	.334	.865	1.199
Rainfall May 10 to September 3 ... foot	....	....	.45
Total depth of water received during growth ... feet	....	....	1.649
Number of irrigators	1	1	....
Average head of water used ... cubic feet per second	.784	2.154	....
Average distance between field laterals ... feet	....	....	78

EXPERIMENT NO. 6.

For the past five years a regular rotation of crops has been conducted on a tract of land 1,227 feet long and 218 feet wide on the experiment station farm. This tract is divided lengthwise into six equal plats of 1 acre each. The order of rotation is barley, clover, wheat, peas, oats, and sugar beets.

During the past year it was found inconvenient to keep the water separate when irrigating each acre, and experiment No. 6 represents a

mixed crop of 1 acre each of wheat, barley, and clover. The yield of wheat was 42.9 bushels, barley 61.5 bushels, and clover 1.59 tons per acre.

Duty of water on 1 acre of wheat, 1 acre of barley, and 1 acre of clover as shown by experiment No. 6.

Items.	First irrigation.	Second irrigation.	Total.
Date of irrigation	June 28-29	July 15-16	
Duration of irrigation ... hours..	10	13	23
Area irrigated ... acres..	3	3	3
Water used ... acre-feet..	.784	1.514	2.298
Depth of water used in irrigation ... foot..	.261	.505	.766
Rainfall May 15 to September 1 ... do...			.43
Total depth of water received during growth ... feet..			1.196
Number of irrigators	1	1	
Average head of water used ... cubic feet per second..	.949	1.409	

EXPERIMENT NO. 7.

This experiment gives the results obtained from 1 acre of sugar beets which formed a part of the rotation previously described. The seed was sown late and the yield was only 10 tons per acre.

Duty of water on sugar beets as shown by experiment No. 7.

Items.	First irrigation.	Second irrigation.	Third irrigation.	Total.
Date of irrigation	July 13-14	July 29-30	Aug. 16-17	
Duration of irrigation ... hours..	24.8	17.5	21	63.3
Area irrigated ... acres..	1	1	1	1
Water used ... acre-feet..	.377	.588	.498	1.463
Depth of water used in irrigation ... feet..	.377	.588	.498	1.463
Rainfall ... foot..				.59
Total depth of water received during growth ... feet..				2.053
Number of irrigators	1	1	1	
Average head of water used, cubic feet per second	.184	.407	.287	
Average distance between field laterals[a]				

[a] Irrigated by furrows.

EXPERIMENT NO. 8.

This field of 15⅓ acres is located in the northeast quarter of the experiment station farm. It was seeded to oats May 16. The crop was cut August 27 and yielded at the rate of 73 bushels per acre. The quantities of water applied in two irrigations are given in the following table:

Duty of water on oats as shown by experiment No. 8.

Items.	First irrigation.	Second irrigation.	Total.
Date of irrigation	June 28–July 2	July 16-17 July 22-25	....
Duration of irrigation ....hours..	91.5	93.75	185.25
Area irrigated ....acres..	15.35	15.35	15.35
Water used ....acre-feet..	12.154	12.782	24.936
Depth of water used in irrigation ....feet..	.792	.833	1.625
Rainfall May 16 to August 27 ....foot..	....	....	.43
Total depth of water received during growth ....feet..	....	....	2.055
Number of irrigators	1	1	....
Average head of water used ....cubic feet per second..	1.607	1.650	....
Average distance between field laterals ....feet..	....	....	68

EXPERIMENT NO. 9.

For three successive years experiments have been made to determine the quantity of water applied to a field belonging to Mr. J. L. Patterson. The results of the three years briefly summarized are as follows:

Depth of water used on farm of J. L. Patterson.

Year.	Crop.	Depth.
		Feet.
1899	Oats	1.72
1900	....do	1.23
1901	Clover	1.57

Three tons of cured hay per acre was the yield for 1901. The data pertaining to this experiment are given in the following table:

Duty of water on clover as shown by experiment No. 9.

Date of irrigation	June 21–25
Duration of irrigation ....hours..	96
Area irrigated ....acres..	27.84
Water used ....acre-feet..	26.40
Depth of water used in irrigation ....foot..	.95
Rainfall May 1 to September 1 ....do...	.62
Total depth of water received during growth...feet..	1.57
Number of irrigators	1
Average head of water used ....cubic feet per second..	3.33

EXPERIMENT NO. 10.

This field is located in the southwest corner of the experiment station farm. Barley was raised on nearly 12.5 acres, of which about 4 acres were occupied with plats. The yield was 59 bushels per acre.

Duty of water on barley as shown by experiment No. 10.

Date of irrigation	July 2–3; July 5–6
Duration of irrigation ....hours..	58.5
Area irrigated ....acres..	12.47
Water used ....acre-feet..	10.55
Depth of water used in irrigation ....foot..	.846
Rainfall May 16 to September 10 ....do...	.46
Total depth of water received during growth ....feet..	1.306
Number of irrigators	1
Average head of water used ....cubic feet per second..	2.18
Average distance between field laterals ....feet..	75

EXPERIMENT NO. 11.

The water applied to a field of peas located in the northwest part of the experiment farm was also determined. The seed was sown May 11 and the yield of straw and peas was 3.8 tons per acre, and of peas alone 37.5 bushels per acre. The results of the irrigation experiment are given in the following table:

Duty of water on peas as shown by experiment No. 11.

Date of irrigation	July 8–9
Duration of irrigation ....hours..	21.25
Area irrigated ....acres..	8.405
Water used ....acre-feet..	2.947
Depth of water used in irrigation ....foot..	.351
Rainfall May 14 to October 1 ....do...	.77
Total depth of water received during growth ....feet..	1.121
Number of irrigators	1
Average head of water used ....cubic feet per second..	1.679
Average distance between field laterals ....feet..	66

EXPERIMENT NO. 12.

Last spring a trapezoidal weir was placed at the highest point of a field 37½ acres in extent, located near Bozeman and owned by State Senator C. W. Hoffman. This oat field was not irrigated until late in the season, when the soil was dry to a considerable depth. A large amount of water was accordingly used, amounting to a trifle more than 15 inches over the entire surface. As there was little waste it shows the capacity of dry soil to absorb and retain water. The chief results of this experiment are included in the following table:

Duty of water on oats as shown by experiment No. 12.

Date of irrigation		July 9–23
Duration of irrigation	hours..	343
Area irrigated	acres..	37.30
Water used	acre-feet..	47.31
Depth of water used in irrigation	feet..	1.269
Rainfall, May 15 to August 27	foot..	.45
Total depth of water received during growth	feet..	1.719
Number of irrigators		1
Average head of water used	cubic feet per second..	1.668
Average distance between field laterals	feet..	63

DUTY OF WATER UNDER MIDDLE CREEK CANAL.

The measurements made on this canal in 1899 and 1900 have been continued during the past season. The total area irrigated under this canal in 1901 was 3,186 acres, of which 665 acres were irrigated twice. The daily discharge of the canal was obtained by means of the same rating flume and automatic register that were used during the preceding years. The results are summarized in the following tables:

Daily discharge of Middle Creek Canal, June 3 to September 15, 1901.

Day.	June.	July.	August.	September.
	Acre-feet.	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*
1	84.288	97.678	45.199	43.631
2	84.288	119.490	55.036	43.631
3	97.675	137.835	62.474	45.199
4	84.288	125.936	55.036	45.199
5	84.288	129.902	49.980	51.567
6	76.355	137.835	45.199	51.567
7	74.865	131.885	48.252	43.631
8	76.355	154.693	49.980	48.252
9	73.380	143.785	49.980	45.199
10	74.865	137.835	49.980	45.199
11	74.865	133.869	51.567	49.980
12	69.415	131.885	51.567	48.252
13	71.397	125.936	48.252	53.548
14	71.397	111.061	43.631	55.036
15	60.489	97.675	45.199	48.252
16	48.252	82.305	51.567	....
17	49.980	88.254	53.548	....
18	53.548	82.305	53.548	....
19	56.522	76.355	55.036	....
20	67.430	74.865	56.522	....
21	73.380	69.415	51.567	....
22	65.449	63.960	51.567	....
23	51.567	65.449	51.567	....
24	56.522	67.430	49.980	....
25	65.449	62.474	43.631	....
26	74.865	62.474	43.631	....
27	73.380	58.508	46.606	....
28	90.240	53.548	45.199	....
29	121.969	53.548	46.606	....
30	115.524	48.252	43.664	....
31	....	46.606	45.199	....
Total	2,222.287	2,973.048	1,540.770	718.143

Acreage of irrigated crops under Middle Creek Canal, 1901.

Total area of farms	6,640
Total area irrigated in 1901	3,186
Area watered twice in 1901	665
Area summer-fallowed in 1901	337
Barley	279
Oats	1,055
Wheat	5
Timothy and clover	669
Clover	440
Timothy	710
Other crops	28
Total	3,186

Duty of water under Middle Creek Canal, 1901.

Area irrigated	acres..	3,186
Discharge of canal	acre-feet..	7,454.25
Depth of water used in irrigation	feet..	2.34
Depth of rainfall May 1 to September 30	foot..	.77
Total depth of water received by crops	feet..	3.11

INVESTIGATIONS IN THE BITTER ROOT VALLEY.

The investigations which were begun in 1900 in the upper portion of the Bitter Root Valley (Pl. XXXIII) have been continued, and their scope along certain lines considerably extended. The report for 1900 included the data pertaining to the amount of water used on three large fields and the seepage losses on the Republican Canal. During the past season, owing largely to the valuable cooperation of the managers of the Bitter Root stock farm, the work has been extended to include the duty of water under five canals which water a total area of 15,763 acres.

In the spring of 1900 a gauging station was established near the head of each canal The fine flumes, constructed by the late Hon. Marcus Daly, served admirably for this purpose. There were no registering machines to spare for this section, and daily records were obtained by the ditch riders. Each ditch is well controlled by competent ditch riders who act under the supervision of Mr. M. D. Kippen, and observations were made for the most part twice each day during the irrigation season. Field surveys were made by Mr. Kippen during the fall months to determine the areas irrigated under each canal, and the computations regarding current meter measurements of the canals, rating curves, and daily discharges have all been made in the Bozeman office.

In view of the foregoing statements the results of the experiments on the duty of water under the canals to be described may be considered reasonably accurate. Only a brief summary of all the work performed can be embodied in a report of this character.

DIVERSIFIED FARMING IN THE BITTER ROOT VALLEY.

THE USE OF CANVAS DAMS IN IRRIGATING SUGAR BEETS.

THE USE OF CANVAS DAMS IN IRRIGATING SUGAR BEETS.

and the company sells water to the former shareholders at $15 per share per annum. Each share represents 15 miner's inches. Water is sold to new settlers under the canal at $1.25 per miner's inch. The flow of the canal during the past season varied from 50 to 76 cubic feet per second.

Daily discharge of the Republican Canal, April 14 to August 28, 1901.

Day.	April.	May.	June.	July.	August.
	Acre-feet.	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*
1		120.85		104.74	82.92
2		109.44		110.38	87.58
3		98.58	36.10	116.10	92.54
4		88.61	33.92	116.10	109.10
5		90.75	36.10	121.95	122.65
6		103.74	40.46	123.65	125.67
7		113.99	40.46	123.65	128.83
8		122.72	40.46	134.58	122.65
9		123.87	36.10	144.10	122.65
10		122.72	31.73	140.83	122.65
11		116.97	31.73	134.38	122.65
12		96.10	36.10	128.03	161.54
13		93.77	38.18	123.65	161.54
14	55.14	115.14	36.10	120.73	122.65
15	58.90	123.97	36.10	116.10	122.65
16	58.90	123.97	42.15	116.10	125.67
17	71.00	123.97	63.47	116.10	122.65
18	81.96	136.56	83.16	116.10	122.65
19	86.67	136.56	98.78	113.36	122.65
20	84.19	112.47	109.08	113.36	119.62
21	84.19	103.74	112.06	116.10	116.90
22	91.82	98.58	129.92	116.10	116.90
23	102.63	93.42	146.06	116.10	121.43
24	116.32	98.58	146.06	120.73	87.32
25	119.35	103.74	139.53	117.88	79.80
26	119.35	109.39	126.89	110.38	105.54
27	119.35	115.09	114.80	107.41	105.54
28	119.35	117.92	114.80	104.74	108.21
29	119.35		112.06	104.74	
30	119.35		103.43	110.38	
31				97.10	
Total	1,607.82	3,115.21	2,115.79	3,655.65	3,263.15

Duty of water under the Republican Canal, 1901.

Area irrigated	acres	4,105
Water used	acre-feet	13,757.62
Average depth of water applied	feet	3.35

DUTY OF WATER UNDER THE HEDGE CANAL.

The Hedge Ditch was originally built by Mr. Hedge to divert water from Skalkaho Creek. Several years ago Mr. Daly purchased the interests of Mr. Hedge and extended the canal up the valley by means of flumes to tap the Bitter Root River. There are about 5 miles of flumes (Pl. XXXVI) on this canal, 7 feet 7 inches wide by 3 feet 7 inches high, inside measurement, and 1,100 feet of redwood stave pipe 36 and 42 inches in diameter. This canal is 24 miles long and irrigated during the past season 5,260 acres of the first bench lands, immediately above the areas covered by the Republican Canal. The maximum flow for the past season was 211.22 cubic feet per second, and occurred May 20 and 21.

DIVERSION DAM ACROSS THE BITTER ROOT RIVER AT THE HEAD OF THE REPUBLICAN CANAL.

A TYPE OF THE BITTER ROOT IRRIGATION FLUMES.

Daily discharge of the Hedge Canal, April 11 to August 31, 1901.

Day.	April.	May.	June.	July.	August.
	Acre-feet.	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*
1		162.43		175.92	157.28
2		140.91		184.06	165.20
3		151.63		143.69	173.15
4		157.09		146.56	175.82
5		146.37		194.87	178.50
6		146.37		199.92	175.82
7		146.37		199.92	165.20
8		143.60		202.70	162.54
9		140.82	88.46	202.70	173.15
10		132.89	119.49	199.92	175.82
11	39.67	124.94	130.21	199.92	173.15
12	51.27	122.17	135.46	199.92	173.15
13	62.87	119.39	130.21	199.92	173.15
14	77.65	122.17	114.14	194.87	173.15
15	92.43	124.94	103.33	189.82	173.15
16	82.22	135.66	114.14	189.82	173.15
17	72.00	157.09	124.94	189.82	173.15
18	72.00	183.86	127.53	189.82	170.47
19	82.22	205.57	148.95	189.82	167.79
20	103.24	211.22	178.80	189.82	167.79
21	114.04	200.52	194.88	192.40	167.79
22	119.49	184.16	189.22	194.97	189.51
23	130.21	178.50	184.16	192.40	211.22
24	143.60	178.50	189.82	189.82	211.22
25	154.51	178.50	184.16	200.52	211.22
26	157.28	178.50	173.15	157.27	184.27
27	157.28	178.50	167.78	103.31	157.28
28	157.28	178.50	167.78	119.39	157.28
29	157.28		167.78	135.46	157.28
30	167.88		167.78	146.37	157.28
31				157.28	157.28
Total	2,194.42	4,431.17	3,302.17	5,573.00	5,382.21

Duty of water under the Hedge Canal, 1901.

Area irrigated	acres	5,260
Water used	acre-feet	20,882.97
Average depth of water applied	feet	3.97

DUTY OF WATER UNDER THE WARD CANAL.

The Ward Canal diverts water from Skalkaho Creek, a tributary of the Bitter Root. It is the third in elevation of the five canals under consideration. This canal was originally begun by a Mr. Ward, whose rights were purchased and subsequent extensions made by Mr. Daly. It is 7 miles long, has a bottom width of about 8 feet, and is built on a grade of 5.28 feet per mile. The maximum flow during the past season was 70 cubic feet per second, and occurred May 10 to 11, inclusive.

Daily discharge of the Ward Canal, April 11 to August 31, 1901.

Day.	April.	May.	June.	July.	August.
	Acre-feet.	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*
1		69.42		107.90	29.16
2		78.34		107.90	22.81
3		88.26		107.90	22.81
4		107.90	69.42	51.77	22.81
5		107.90	78.34	97.78	22.81
6		107.90	97.78	97.78	13.29
7		118.41	97.78	88.26	17.65
8		118.41	97.78	97.78	13.29
9		118.41	88.26	97.78	13.29
10		138.84	88.26	69.42	13.29
11	22.81	138.84	51.77	69.42	13.29

Daily discharge of the Ward Canal, April 11 to August 31, 1901—Continued.

Day.	April.	May.	June.	July.	August.
	Acre-feet.	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*
12	22.81	118.41	51.77	60.30	13.29
13	22.81	118.41	60.60	51.77	13.29
14	22.81	118.41	69.42	43.64	6.74
15	17.65	118.41	78.34	51.77	6.74
16	22.81	107.90	78.34	51.77	6.74
17	22.81	107.90	97.78	51.77	6.74
18	22.81	107.90	107.90	51.77	6.74
19	17.65	107.90	107.90	60.30	13.29
20	17.65	107.90	107.90	51.77	13.29
21	29.16	97.78	107.90	51.77	13.29
22	29.16	97.78	118.41	43.64	13.29
23	29.16	88.26	118.41	69.42	13.29
24	35.90	88.26	107.90	69.42	13.29
25	43.64	107.90	107.90	69.42	13.29
26	51.77	107.90	107.90	51.77	13.29
27	35.90	107.90	107.90	51.77	13.29
28	35.90	107.90	107.90	51.77	13.29
29	35.90	....	107.90	51.77	13.29
30	51.77	....	107.90	43.64	13.29
31	....	....	....	35.90	13.29
Total	590.88	3,009.45	2,529.36	2,058.84	437.55

Duty of water under the Ward Canal, 1901.

Area irrigated	acres..	3,587.00
Water used	acre-feet..	8,626.08
Average depth of water used in irrigation	feet..	2.41

DUTY OF WATER UNDER THE SKALKAHO CANAL.

This is one of the new canals of the Bitter Root stock farm and diverts water from Skalkaho Creek. The Ward and Skalkaho canals convey all the flow of this creek with the exception of about 5 cubic feet per second, which is used as a domestic supply by Hamilton City. The length of this canal is 7 miles, of which 2½ miles are flumes, and two ravines are crossed by means of inverted redwood stave-pipe siphons 36 inches in diameter. The size of the flume is 4 feet 8 inches wide inside by 2 feet 8 inches high. The grade throughout is 5.28 feet per mile.

From the latter part of April to the latter part of August the flow in this canal varied from 20 to 41.5 cubic feet per second.

Daily discharge of Skalkaho Canal, April 12 to August 31, 1901.

Day.	April.	May.	June.	July.	August.
	Acre-feet.	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*
1	....	44.63	....	77.75	68.82
2	....	44.63	....	77.75	68.82
3	....	44.63	....	51.87	65.06
4	....	51.17	....	54.15	59.50
5	....	57.71	....	82.31	57.72
6	....	57.71	....	82.31	57.72
7	....	57.71	43.64	82.31	57.72
8	....	61.19	61.29	82.31	54.35
9	....	69.02	62.97	80.03	52.66
10	....	73.39	64.66	75.57	54.35
11	....	73.39	66.74	69.02	52.66
12	16.26	77.84	56.72	64.66	50.98
13	16.26	82.31	44.63	64.66	49.49
14	16.26	82.31	44.63	62.97	48.00

Daily discharge of Skalkaho Canal, April 12 to August 31, 1901—Continued.

Day.	April.	May.	June.	July.	August.
	Acre-feet.	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*
15	16.26	80.03	44.63	61.29	46.31
16	17.75	77.75	44.63	61.29	44.63
17	19.24	77.75	44.63	71.80	44.63
18	19.24	67.73	51.17	82.31	41.90
19	19.24	57.71	57.72	82.31	39.17
20	19.24	57.71	61.19	82.31	39.17
21	22.61	57.71	64.66	82.31	39.17
22	26.88	57.71	69.02	82.31	37.92
23	30.64	57.71	73.39	77.85	36.69
24	34.51	57.71	73.39	77.85	36.69
25	36.10	57.71	73.39	82.31	35.60
26	36.10	61.19	73.39	77.85	34.51
27	36.10	64.66	73.39	73.39	34.51
28	38.42	64.66	73.39	73.39	34.51
29	41.39	....	75.57	73.39	34.51
30	44.13	....	77.75	71.10	34.51
31	....	....	....	68.82	34.51
Total	506.13	1,775.38	1,476.59	2,289.55	1,446.79

Duty of water under Skalkaho Canal, 1901.

Area irrigated	acres	1,600
Water used	acre-feet	7,494.44
Average depth of water applied	feet	4.68

DUTY OF WATER UNDER GIRD CREEK CANAL.

This small canal is about 4 miles long and has a grade of 5.28 feet per mile. There are 1,500 feet of flumes, which are 4 feet 8 inches wide and 2 feet 8 inches high, inside measurements.

The maximum flow occurred from June 20 to 27 and was 20 cubic feet per second.

Daily discharge of Gird Creek Canal, May 7 to July 20, 1901.

Day.	May	June.	July.	Day.	May.	June.	July.
	Acre-feet.	*Acre-feet.*	*Acre-feet.*		*Acre-feet.*	*Acre-feet.*	*Acre-feet.*
1	....	5.157	40.464	18	23.404	34.513	16.463
2	....	5.157	38.976	19	23.404	37.488	12.394
3	....	7.835	20.132	20	23.404	40.464	10.513
4	....	10.513	20.132	21	23.404	40.464	....
5	....	10.513	36.001	22	23.404	40.464	....
6	....	12.397	34.513	23	35.108	40.464	....
7	7.537	14.281	34.513	24	35.108	40.464	....
8	7.537	14.281	34.513	25	23.404	40.464	....
9	7.537	14.281	36.001	26	23.404	40.464	....
10	7.537	14.281	37.488	27	23.404	33.026	....
11	7.537	14.281	36.001	28	23.404	25.588	....
12	7.537	18.843	34.513	29	14.281	33.026	....
13	7.537	23.404	34.513	30	5.157	33.026	....
14	7.537	23.404	34.513	31	5.157	....	....
15	10.909	23.404	31.637				
16	18.843	26.084	26.084	Total	418.899	749.668	590.389
17	23.404	31.637	21.025				

Duty of water under Gird Creek Canal, 1901.

Area irrigated	acres	1,211
Water used	acre-feet	1,758.956
Average depth of water applied	feet	1.452

FIELD EXPERIMENTS ON THE BITTER ROOT STOCK FARM.

The results of experiments made on three fields in the Bitter Root Valley were given in the report for 1900. The trapezoidal weirs being in place, these tests were continued during the past season.

The records of rainfall were obtained from Mr. G. W. Dougherty, weather observer at Corvallis, a few miles distant. The data pertaining to experiment No. 1, made on a 40-acre tract of 6-year-old orchard trees are given in the following table:

Duty of water as shown by weir test No. 1.

Items.	First irrigation.	Second irrigation.	Third irrigation.	Fourth irrigation.	Total.
Date of irrigation	Apr. 15–18	June 27–30	Aug. 13–18	Sept. 1–2	....
Duration of irrigation......hours..	74	74	114	21.5	283.5
Area irrigated......acres..	40	40	40	40	40
Water used......acre-feet..	16.92	13.72	28.72	2.95	62.31
Average depth of water used in irrigation......feet..	.42	.34	.72	.07	1.56
Rainfall......foot..	....	....	....	....	.49
Total depth of water used during growth......feet..	....	....	....	....	2.05
Number of irrigators	1	1	1	1	....
Average head of water used, cubic feet per second	2.77	2.24	3.05	1.66	....

Measurements were made of the water used on a field located on the Prendergast ranch, containing 161.7 acres. Last year it was seeded to timothy and clover, with oats as a nurse crop. The yield of clover hay during the past season was 150 tons. The rainfall during the irrigation season was about 6 inches and water to the depth of 18 inches was applied in three irrigations, thus making a total depth over the surface irrigated of 24 inches.

Duty of water as shown by weir test No. 2.

Items.	First irrigation.	Second irrigation.	Third irrigation.	Total.
Date of irrigation	May 11–28	June 22–July 2.	Aug. 29–Sept. 8.	....
Duration of irrigation......hours..	404	241.5	241	886.5
Area irrigated......acres..	161.7	161.7	161.7	161.7
Water used......acre-feet..	95.72	51.57	94.83	242.12
Average depth of water applied......feet..	.59	.32	.59	1.50
Rainfall......foot..	....	....	....	.49
Total depth of water used during growth, feet	....	....	....	1.99
Average head of water used, cubic feet per second.	2.87	2.58	4.76	....

Another experiment was made on a field containing 102 acres located on a high gravelly bench of the Gilchrist ranch. Last year a crop of oats was raised on the same field and this year it produced 103 tons of clover hay.

The rainfall was nearly 5.5 inches and the average depth of water applied in four irrigations 26.5 inches, making a total of 32 inches. The results of this experiment are given in the following table:

Duty of water as shown by weir test No. 3.

Items.	First irrigation.	Second irrigation.	Third irrigation.	Fourth irrigation.	Total.
Date of irrigation	Apr. 20-May 2.	May 4-16, 21-30.	June 11-July 3.	July 29-Aug. 13.	....
Duration of irrigation......hours	152.5	119.8	271	157.5	700.8
Area irrigated..............acres	102	102	102	102	102
Water used..............acre-feet	38.88	40.94	66.96	79.75	226.58
Average depth of water applied, feet	.38	.40	.66	.78	2.22
Rainfall.......................foot					.45
Total depth of water received during growth.......feet					2.67
Average head of water used, cubic feet per second	3.09	4.14	2.99	6.13	....

UTAH.

IRRIGATION IN BEAR RIVER VALLEY, UTAH, 1901.

By Arthur P. Stover,
Assistant in Irrigation Investigations.

INTRODUCTION.

The Bear River Valley is situated in Boxelder County, in the northern part of the State of Utah, and forms the northern extremity of Great Salt Lake Valley. It embraces as fertile an area of agricultural land as can be found anywhere in the intermountain region. This valley is about 27 miles long north and south, and 10 or 12 miles wide east and west. On the east it is bounded by the high single spur range of the Wasatch Mountains which separates it from Cache Valley, while on the west the low rolling hills of the Promontory Range form its boundary. From the shores of Great Salt Lake on the south the valley stretches northward to a point about 15 miles south of the Utah-Idaho line, at which point the two ranges above mentioned close in and form the northern boundary of the valley.

Bear River, from which the valley derives its name, enters the valley at its northeastern corner. From the mouth of the canyon the river takes a winding course, flowing generally in a southerly direction through the east half of the valley, and empties into Great Salt Lake about 8 miles southwest of the town of Corinne. Malade River, a tributary of Bear River, enters the valley also from the north and, flowing also in a southerly direction, joins the Bear near the settlement of Bear River City, located 4 miles north of Corinne. With the exception of a few small springs and streams entering the valley from the east, these two rivers form the sole water supply for the 250 square miles of arable land confined within the boundaries of the valley. For irrigation purposes the Malade is of comparatively little importance on account of the extremely alkaline nature of its water. Watering wild hay along the river bottoms is about the only use that can be made of Malade River water.

The area of land susceptible of irrigation approximates 100,000 acres. Of this area between 20,000 and 25,000 acres lie on the east side of the river, and about 75,000 acres on the west side.

The altitude of the arable sections of the valley above sea level varies from 4,200 feet at the shores of the lake to about 4,500 feet in the northern part of the valley in the vicinity of Fielding. The climate is such that all crops common to the intermountain region can be successfully grown.

The soils of the valley vary from a light gravelly loam near the foothills to the deep, heavy alluvial deposit in the central part of the valley, which was at the bottom of the prehistoric Lake Bonneville, the ancient shore lines of which may be plainly seen on the mountains surrounding the valley, several hundred feet above the present lake level. The soils throughout the valley are of high fertility. Every locality, almost without exception, has good drainage either into the Malade River bottoms or the Bear River bottoms, both of which lie from 40 to 100 feet below the general level of the valley.

BEAR RIVER.[a]

Bear River has a watershed of approximately 6,000 square miles, lying in northeastern Utah, southwestern Wyoming, and southeastern Idaho. The river rises in the Uinta Mountains in the northeastern part of Utah near the sources of the Duchesne, Weber, and Provo rivers. From its source the river takes a northerly course, and following the State boundary between Wyoming and Utah enters the southeastern corner of Idaho. After flowing thence in a northwesterly direction for nearly 50 miles it turns abruptly to the south and reenters the State of Utah at the northern extremity of Cache Valley. All along its course the river is fed by numerous tributaries which head high up in the mountains and furnish a steady supply to the main stream. In Cache Valley the river is fed by Logan and Blacksmith Fork rivers, the low-water flow from either of which seldom if ever falls below 100 or 125 cubic feet per second.

Near the center of the west side of Cache Valley the river enters Bear River Canyon, and after flowing through this narrow box canyon, in which the fall is from 60 to 80 feet per mile, it enters Bear River Valley. After flowing nearly the entire length of the valley between high bluffs it discharges into Great Salt Lake.

CANAL SYSTEMS.

Prior to the construction of the Bear River Canal there were but one or two small ditches taking water from Bear River below the canyon for irrigation purposes. As this report deals only with the investigations under the Bear River Canal (Map, Pl. XXXVII), which supplies water to the west side of the valley, nothing will be said of irrigation from

[a] For complete description of Bear River and tributaries, see U. S. Dept. Agr., Office of Experiment Stations Bul. 70.

other sources other than that the supply from the few creeks and springs previously mentioned is wholly inadequate to supply the land that could be farmed were the water supply larger.

The Bear River Canal enterprise had its beginning in 1889, when the Bear Lake and River Waterworks Company was organized for the purpose of reclaiming lands lying on both sides of the valley. Large twin canal systems were planned, one to convey water to the land on the west side of the river, the other to furnish water to the east side of the valley and extending south as far as Ogden. Bear Lake on the upper reaches of Bear River was filed on as a reservoir site in which to store water to insure against shortage in seasons of drought. Portions of the west side of Cache Valley lying just north of the Bear River Valley were also to be irrigated with water controlled by this company.

Numerous estimates and careful surveys were made; the flow of Bear River was carefully investigated, and it was found that during ordinary seasons its flow at the mouth of the canyon would be adequate for the demands which would be likely to be made upon it. With the assurances of an ample water supply and a favorable outlook as to the rapid settlement of the land to be reclaimed, the construction of the twin canal systems was begun. The canal on the west side of the river, with its main branches and distributing sects, was constructed and put in operation. The canal on the east side of the river, however, has never been completed.

For several years the Bear Lake and River Waterworks Company, the original projector of the enterprise, was in financial straits and its properties were not in use. In 1894 the original company failed, and in September of the same year a receiver was appointed to take charge of its affairs. Soon after, the Bear River Irrigation and Ogden Waterworks Company was formed for the purpose of reviving the enterprise. This management also failed of success, and in April, 1899, the entire property was sold under foreclosure for $120,000. The original cost approximated $2,500,000. This sale resulted in a third reorganization, when the Bear River Water Company was formed to assume control of and revive the enterprise which had thus far proved such a failure. This new company immediately set about to put the system upon a paying basis. During the several years the system had remained comparatively idle structures along the canal line which need constant care were allowed to go to ruin, with the result that the entire system was in need of extensive repairs. As it was almost time for the irrigation season to commence when this company came into control of the system, heavy but temporary repairs were made where most needed in order to place the system in condition to supply water during the season. The work of permanent improvement was immediately begun and continued during the remainder of the season and the following winter. In this short period $125,000 was spent in the

permanent betterment of the system, with the result that to-day t canal system is in better condition than it ever was, and when oth contemplated repairs are made the system will be in shape to me every demand that will be made upon it. Pl. XXXVIII shows t character of some of the reconstruction work done during 1900–190

In May, 1901, the canal property again changed hands. This tin the Utah Sugar Company, a corporation capitalized at $2,000,000, w the purchaser. The consideration in the transaction was $300,00 By this change this corporation came into possession of the immen canal system and the principal part of the unsold land under the cana amounting to several thousand acres. The name Bear River Wat Company was retained as the name of the branch corporation in co trol of the canal property.

The dam and headworks for the twin canals were located just belo the point where Bear River leaves Cache Valley and enters Bear Riv Canyon. The site chosen was an admirable one. A 370-foot crib da was drift bolted to the solid rock abutments on either side of th canyon and the almost continuous rock formation found but a sho distance below the original bed of the channel. This dam raises th water of the river 18 feet above its original bed and diverts it into th canals on either side of the river.

For the first 1¾ miles from the head gate the west side canal i built in almost solid rock which forms the side of the canyon. I this distance there are six tunnels, 14 by 14 feet in cross section, an varying in length from 57 to 279 feet. The canal in the canyon sec tion has a bottom width of 14.3 feet and an average depth of 10 fee with side slopes nearly vertical. At points along the line where th slopes of the canyon walls were too steep to allow the entire chann to be cut in them, rubble masonry and concrete retaining walls (P XXXVIII, figs. 1 and 2) were built on the lower side of the channe These retaining walls were given a width of 7.5 feet at grade lin were made 2.5 feet thick at the top, and given a height of 10 fee Throughout the canyon section the canal has a uniform grade of feet per mile. In this section there are three sets of regulating gate and wasteways.

After leaving the heavy rock work of the canyon section the can is carried for a distance of 3.25 miles along the steep hillside tha bounds the river in a compact earth and clay formation. The botto width of the channel varies from 20 to 25 feet. The sides have a slop of 1 to 1, and the depth is 10 feet. About 5 miles below the head gat the canal gains the top of the river bluff, and a half mile farthe on are located the Corinne division gates (Pl. XXXIX). Here th canal divides into two branches, one, the west line, supplying th west side of the valley, the other, the Corinne line, serving the sec tion of the valley lying between the Malade and Bear rivers and th south end of the valley in the vicinity of Corinne.

FIG. 1.—CONCRETE AND MASONRY CONSTRUCTION, BEAR RIVER CANAL.

FIG. 2.—SIDEHILL CONSTRUCTION, BEAR RIVER CANAL.

CORINNE DIVISION GATES, BEAR RIVER CANAL.

From the division gates the west line takes a northwesterly course for a distance of 3.5 miles to the point at which the canal crosses the Malade River in a wooden flume supported on iron trestles. The maximum height of the flume above the Malade River is 80 feet. The length of the flume is 378 feet in the clear, its inside width is 20 feet, and it is capable of carrying water to a depth of 7 feet. Beyond the Malade flume the canal takes a southwesterly course, and, following the contour of the west side of the valley, passes just above the settlements of Riverside, Garland, and Roweville and empties into Great Salt Lake in the twenty-eighth mile of its course. Between Garland and Roweville there are three vertical drops, each 7 feet in height, inserted in the canal to lose grade. In the eleventh mile from the division gates the central lateral is taken from the west line, and, flowing in a southerly direction, supplies the central portion of the valley lying on the west side of Malade River.

From the division gates the Corinne line flows almost due south, occupying the summit of the divide between Bear and Malade rivers, so that laterals are taken from both sides of the canal. Along its course there are 16 vertical drops, varying in height from 4 to 12 feet. Fourteen miles from the division gates this line crosses the Malade River. The crossing is made in an iron flume, the plate girders forming the sides of the flume. The structure consists of 3 principal spans, the center one being 60 feet in length, the end spans 25 and 45 feet, respectively. The two steel bents or supports are founded on iron cylinders filled with concrete, which in turn rest on piling. During the season of 1897 the wooden structure connecting the earth channel with the south end of the iron flume became undermined by seepage and gave way, causing a washout at that end of the flume. From the Malade flume the Corinne line continues in a southerly direction, passes under the Southern Pacific Railroad tracks at a point 3 miles west of Corinne, then divides into two main laterals, which distribute water to the district lying to the west of Bear River.

The canal which was intended to supply the east side of the valley has never been built beyond the sixth mile. In the canyon section of this line heavy rock and tunnel work was also encountered. The hillside work between the canyon section and the point at which the canal gains the top of the river bluffs, near the town of Collinston, was also a difficult undertaking. These bluffs have a slope of about 3 to 1 and are of practically the same earth and clay formation encountered on the west side of the river. The company which is now in control of the entire Bear River Canal system anticipates the early completion of this east side canal, which, when completed, will give the east side of the valley an abundant water supply, the only thing lacking for a rapid development of that section of the valley.

CANAL ORGANIZATION AND MANAGEMENT.

Since the Bear River Water Company is one of the very few examples of capitalistic irrigation organization to be found in the State of Utah, and as the canal system this company controls ranks among the largest of its kind in the arid West, a short discussion of the organization of this company and a few facts regarding the management of its immense system may be of interest.

The entire control of the canals and the power to transact all business in connection therewith is vested in a board of five directors. This directorate is composed of the president, vice-president, secretary and treasurer, and two directors. The head office of the company is located in Salt Lake City. The direct management and control of the canal system is placed in the hands of a resident manager and a canal superintendent whose headquarters are at Corinne, where the branch office of the company is located. The former officer transacts all canal business that comes properly within the jurisdiction of the branch office. The latter superintends the diversion of water into the canals and its distribution therefrom, is in direct charge of all repairs and reconstruction work on the system, and has general supervision of field work carried on in connection with the system. To aid him in his work the superintendent has an assistant and a number of ditch riders. The former aids in adjusting the flow in various laterals and in the collection of data relative to the use of water under the system. The ditch riders each have charge of a section of canal, which they patrol daily. This close inspection of the canals is for the twofold purpose of attending to the distribution of the water to the irrigators and of detecting any leaks or breaks which if not immediately attended to might in a short time do serious damage.

The original claim of the Bear River Water Company to the water of the river approximates 1,000 cubic feet of water per second. The amount of water actually diverted has at no time in the history of the canal exceeded 500 cubic feet per second. But with the further improvement of the west side canal and the completion of the east side line, it is probable that the amount that will be diverted will equal the original claim.

WATER-RIGHT CONTRACTS.

The contracts entered into between the canal company and water users specify that water sold and supplied to consumers shall, if desired, equal but not exceed 1 cubic foot per second for each 80 acres entitled to water; that the water so supplied shall be used upon the tract of land described in the contract and no other; and that the irrigation season shall begin on May 1 and end on November 1 of each year.

The rates charged for water vary with the nature of the use made of the water. In the contract three classifications are made: (1) For the irrigation of farm lands; (2) for orchards exceeding five years' growth; (3) for city or town lots. The price of the "perpetual right" for land in any of these classes is $20 per acre, while the annual rent per acre for the three classes is $1, $2.50, and $3, respectively. Payment for water rights is made on the installment plan, deferred payments to bear interest until maturity at the rate of 6 per cent per annum, payable annually. The rate after maturity is 12 per cent per annum. Annual rentals are due and payable on or before April 1 of each year.

Section 8 of the contract refers to the distribution of water from the canal to consumers. The entire paragraph is given below:

8. The water shall be governed and regulated by the company, who shall notify said consumer of the time for the use of said water, or said company, at its option, may give said consumer a continuous flow, who shall use the same without material waste. All gates, weirs, and other belongings for the distribution of said water on the company's canals and laterals shall be owned and are under the control of the said company. The said water shall be delivered by said company into a lateral or ditch to be provided by said consumer, from a box or weir through the banks of the said company's canal or lateral, to be provided by it. Said consumer agrees to use no more water than this contract authorizes and at such stated times as shall be designated by the said company and distributed by the water master, nor shall the consumer furnish any water to any other person on land not herein described; and any violation of these provisions shall forfeit the right of the consumer to the use of water during the remainder of the irrigation season.

It will be noticed that this paragraph provides that water may at the option of the company be distributed either by a continuous flow or by rotation. This feature is one to be highly commended. Under large laterals a continuous flow can be used advantageously, and with care on the part of the irrigators little waste results from this method of distribution. Under a small lateral, however, say where the flow, if continuous, would be less than 1 cubic foot per second, both the irrigator and the canal company would be losers, since a continuous flow of this size could not be used effectively or economically. By the rotation system on small laterals each irrigator is given a good stream for a period of time in proportion to his rights in the canal, and when his period of use is at an end some other irrigator receives the stream. This method is very efficient, and is one which not only effects a saving in the amount of water used, but also reduces the time and labor required of an irrigator in the watering of his crops.

Paragraph 9, given below, relieves the canal company of liability in case of shortage of water, and provides for a pro rata distribution among water users in case of such shortage:

9. In case of shortage of water in the company's canal through accident, drought, or scarcity in any natural stream supplying said canal, or by reason of improper diversion of water by any person, or from any other cause beyond its control, the

company shall not be liable for such shortage or for any damage caused thereby, nor shall there be by reason thereof any deduction from any sum herein agreed to be paid by the consumer. In case of any such shortage the company may alternate the water carried through its canal under or pursuant to this or similar contracts, or may distribute it pro rata to all its consumers who shall hold contracts for the carriage through said canal of water flowing therein in accordance with such rules and regulations as it may from time to time deem necessary and expedient.

Paragraph 10 further relieves the company of liability for damages to irrigated lands under the canal by reason of any leakage or overflow from the canal or its laterals:

10. The consumer agrees * * * to waive and hereby does waive any and all claims for loss or damages by reason of any leakage or overflow from said canals, ditches, or laterals of said company, either upon the land aforesaid or any other tract belonging to said consumer. If any of the land described herein be above the grade of the canal the measure of damages shall be the amount paid for such water.

The last sentence refers to land that can not be irrigated from the canal by reason of its location, and provides for the refunding of the amount paid for a water right for such lands.

SEEPAGE INVESTIGATIONS.

The loss of water from the canal by seepage and evaporation is a matter of great importance. This is true whether the water supply is abundant or limited. Under the former condition, although the loss is not directly felt, sooner or later the effect is noticed in sections lying along the canal which gradually become swampy and worthless. Under the latter condition the loss to both the irrigator and canal owner is so apparent as to scarcely need mentioning. With a canal's water supply barely sufficient for the demands made upon it, the diminution of such supply without beneficial results is a matter which demands the attention of all canal owners as well as irrigators.

During the latter part of June measurements were made on the Bear River to determine the extent of losses of water in various sections of the canal.

In an investigation of this sort there are always three things for which to look: (1) The amount of loss in given sections of the canal; (2) the exact or approximate location where the loss is greatest, determined by dividing the canal into sections and determining the seepage in each separately, and (3) possible remedies for such losses when determined.

The method of determining the loss from any section of the canal consisted in obtaining the inflow at the upper end of the section and the total outflow from the section, which includes the amount diverted by laterals as well as the outflow at the end of the section. The difference between the inflow and the total outflow is the loss. As the time intervening between the upper and lower measurements of any section was in no case more than three or four hours, the amount of evapor-

ation from the surface of the canal during the period of observation was extremely small, and in the following results this loss has not been considered separately, but only as a part of the total loss from all causes.

In the following discussion of the results obtained, frequent comparison is made with the results[a] obtained by similar measurements made during the season of 1900, by Mr. C. T. Johnston, of this Office. The method used in both cases was substantially the same, so that the variation in the amounts of seepage in the several sections may be taken as representing the change in the condition of the canal channel in a year.

LOSSES FROM MAIN CANAL.

The main line was divided into three sections, the first one extending from the head gate to flume No. 1, a distance of 1.5 miles. This section included all the canyon section. The second section extended from flume No. 1[b] to flume No. 3, a distance of 0.75 mile, and the third section extended from flume No. 3 to the end of the main line at the Corinne division gates, a distance of 3.25 miles.

The first section is for the most part in heavy rock work; a portion of the line, however, is built in a rather coarse disintegrated limestone formation, and in this material the loss by seepage is considerable. Aside from the leakage at overflows Nos. 1 and 2 there were no diversions made from the canal in the first section. The results of the measurements made in this section are as follows:

Losses from first section of main canal, June 25, 1901.

[In cubic feet per second.]

Discharge at head gate		279.34
Diversions:		
Overflow No. 1	0.75	
Overflow No. 2	1.00	
Discharge at flume No. 1	263.56	
		265.31
Loss in section		14.03
Loss per mile		9.35
Percentage of loss		5.00

In the second section, from flume No. 1 to flume No. 3, a distance of 0.75 mile, the channel follows the side hill bounding the river bottom.

[a] U. S. Dept. Agr., Office of Experiment Stations Bul. 104.

[b] During the winter of 1900-1901 extensive repairs were made on the main line of the canal and a number of the old flumes were replaced by substantial concrete and rubble masonry channels, thus doing away with a number of flumes in the canyon section, so that what was formerly flume No. 5 is now flume No. 1, and flume No. 9, as renumbered, is flume No. 3.

The material forming the canal channel in this section is also of a porous nature. There are no diversions in this section:

Losses from second section of main canal, June 25, 1901.

[In cubic feet per second.]

Discharge at flume No. 1		263.56
Discharge at flume No. 3		258.36
Loss in section		5.20
Loss per mile		6.93
Percentage of loss		1.90

The loss in these two sections is heavier by far than in any other portion of the system. While it is impossible to prevent the greater part of this loss, owing to the nature and location of the channel, yet a comparison of the loss in 1900 with that of 1901 will show plainly that the improvements made during the winter of 1900–1901 reduced the loss by seepage considerably. In 1900 the loss between the head gate and flume No. 9 (now No. 3) was found to be 10.66 per cent of the amount entering the head of the canal. In 1901 this percentage of loss reached only 6.90 per cent, showing a decided improvement.

The third section of the main line, extending from flume No. 3 to the Corinne division gates, covering a distance of 3.25 miles, is built almost entirely along the side hill bounding the river. The material passed through is of a heavy compact soapstone formation, which when protected from the air remains in its solid form, but when exposed to the action of the atmosphere for any length of time rapidly disintegrates and crumbles into a fine dust. The loss in this section was considerably less than was anticipated on account of the steep slopes of the bluffs.

Losses from third section of main canal, June 25, 1901.

[In cubic feet per second.]

Discharge at flume No. 3		258.36
Diversions, Wheeler lateral	0.75	
Discharge at Corinne division gates	254.72	
		255.47
Loss in section		2.89
Loss per mile		.89
Percentage of loss		1.10

In the same section in 1900 the loss amounted to 2 per cent, showing an appreciable decrease in the loss by the improvements made in this section.

The losses from the whole length of the main line are as follows:

Losses from main canal, June 25, 1901.

[In cubic feet per second.]

Discharge at head gate		279.34
Diversions	2.50	
Discharge at Corinne division gates	254.72	
		257.22
Loss in section		22.12
Loss per mile		4.02
Percentage of loss		7.92

The loss in the same section as measured in 1900 was found to be 12.48 per cent, showing a decrease of over 4.5 per cent in the amount of loss.

One noticeable feature in the canyon section is the tendency of the channel to become less porous as the season advances. No measurements have been made to prove this theory, but at several points along the canyon section small streams of water issue from the side hill under the canal. During the fore part of the season the discharge from these sources is considerable and as the season advances the flow gradually decreases and in many instances ceases altogether, showing almost conclusively that tne previous condition of the channel, caused by frost and other natural agencies during the winter season when the canal is empty, is gradually overcome by the silting of the channel by the heavily silt-laden water admitted to the canal during the early part of the season.

LOSSES FROM THE WEST LINE OF BEAR RIVER CANAL.

About one-half mile above the Corinne division gates the canal leaves the river bluffs and gains the general level of the valley. From here on the loss by seepage is not so apparent as in the canyon section. Throughout the entire length of the west line the water section of the canal is entirely in excavation, and hence the loss by seepage through the banks is reduced to a minimum. The first section of this line extended from the Corinne division gates to the Malade flume, a distance of 3.5 miles. The losses in this distance were as follows:

Losses from the first section of the west line, June 25, 1901.

[In cubic feet per second.]

Discharge at Corinne division gates		138.59
Diversions:		
Box No. 1	0.10	
Box No. 2	.10	
Box No. 5	2.65	
Box No. 10	.08	
Discharge at Malade flume	137.54	
		140.47
Gain in section		1.88
Gain per mile		.54
Percentage of gain		1.36

This was the only section in the whole canal in which the measurements showed a gain in the flow. The measurements of 1900 also showed a gain in this section, but at that time the gain reported was considered due to an error in measurement. As the measurements of 1901 also show this increase, it is highly probable that the canal in this section receives an inflow from some source. The amount of this

inflow or the location of its entrance into the canal can only be surmised. Judging from the nature of the surrounding country, there is no reason to believe that the loss from the canal in this section should be materially different from that of any other section, and that such loss is more than compensated by this inflow shows that the amount of water reaching the canal from underground sources is considerable.

Although there are no external evidences of underground water in the immediate vicinity of the canal, yet near Fielding there are several small ravines which collect water that comes either from underground scources or from the irrigated lands in that vicinity. Another evidence of the presence of underground water is the number of small springs and seepy places found along the Malade River bottoms, which undoubtedly derive their water from other sources than the irrigated lands above, since many of the springs and bog holes in this locality existed prior to the construction of the canal.

In the second, third, and fourth sections of the west line, extending from the Malade flume to Roweville, and covering collectively a distance of about 12 miles, the conditions affecting loss by seepage are almost identical. Throughout the entire distance the wetted section of the canal is in excavation, but little variation occurs in either cross section, grade, or velocity, and the soil conditions throughout the section are practically uniform.

The second section extended from the Malade flume to bridge No. 13, a distance of 2.5 miles. The third section extended from bridge No. 13 to bridge No. 18 and covered also a distance of 2.5 miles. The losses in these two sections were as follows:

Losses from second and third sections of the west line, June 25, 1901.

[In cubic feet per second.]

Discharge at Malade flume		137.54
Diversions:		
Box No. 15	3.38	
Box No. 25	.08	
Box No. 30	.22	
Box No. 35	2.61	
Discharge at bridge No. 13	129.41	
		135.70
Loss in section		1.84
Loss per mile		.74
Percentage of loss		1.34
Discharge at bridge No. 13		129.41

Diversions:		
Box No. 45	0.72	
Box No. 55	2.70	
Box No. 62	5.59	
Box No. 65	2.41	
Box No. 70	.05	
Box No. 75	3.45	
Box No. 85	2.36	
Discharge at bridge No. 18	109.99	
		127.27
Loss in section		2.14
Loss per mile		.86
Percentage of loss		1.65

In the fourth section, extending from bridge No. 18 to Roweville and covering a distance of 7 miles, the loss was as follows:

Losses from fourth section of the west line, June 26, 1901.

[In cubic feet per second.]

Discharge at bridge No. 18		109.99
Diversions:		
Box No. 90	2.51	
Box No. 95	4.00	
Box No. 104	1.75	
Box No. 105	.05	
Central lateral	39.81	
Box No. 110	.30	
Box No. 115	.40	
Box No. 125	5.76	
Box No. 130	3.11	
Box No. 140	4.57	
Discharge at Roweville Bridge	43.26	
		105.52
Loss in section		4.47
Loss per mile		.64
Percentage of loss		4.06

With the exception of the first 3.5 miles of the west line there is a gradual decrease of the flow of the canal. This loss is greatest just above Garland, 0.86 cubic foot of water per second per mile. The loss in the upper 15.5 miles of the west line from the division gates to Roweville is as follows:

Losses from west line, June 25–26, 1901.

[In cubic feet per second.]

Discharge at division gates		138.59
Diversions:		
First section	2.93	
Second section	6.29	
Third section	17.28	
Fourth section	62.26	
Discharge at Roweville Bridge	43.26	
		132.02
Loss in section		6.57
Loss per mile		.42
Percentage of loss		4.74

It was thought that the percentage of loss from the west line would be much larger than that given above. But the fact that in the first section there is an appreciable increase in the flow of the canal would lead to the belief that the other sections receive small amounts of water from underground sources, thus decreasing the net loss.

LOSSES FROM THE CORINNE LINE OF BEAR RIVER CANAL.

The portion of the Corinne line on which the losses were determined extended from the Corinne division gates to a point about 3 miles west of Corinne. This length of canal was divided in three sections: The first, 8.5 miles in length, extended from the division gates to bridge No. 14; the second section, 5.5 miles in length, extended from bridge No. 14 to the Malade flume, or Red flume, as it is often called; and the third section extended from the Red flume to bridge No. 25, located just north of the Southern Pacific Railroad track. The length of this last section was 3.75 miles.

Losses from first and second sections of Corinne line, June 26, 1901.

[In cubic feet per second.]

Discharge at Corinne division gates		118.94
Diversions:		
Box No. 5	3.95	
Box No. 7	.08	
Box No. 10	.72	
Box No. 15	8.40	
Box No. 25	.20	
Box No. 30	2.29	
Box No. 35	3.76	
Box No. 40	2.88	
Box No. 45	4.14	
Box No. 50	2.58	
Box No. 55	2.87	
Discharge at bridge No. 14	79.70	
		111.57
Loss in section		7.37
Loss per mile		.87
Percentage of loss		6.20
Discharge at bridge No. 14		79.70
Diversions:		
Box No. 60	0.50	
Box No. 65	.08	
Box No. 70	3.25	
Box No, 75	2.53	
Box No. 80	5.06	
Box No. 85	.49	
Box No. 90	2.62	
Box No. 95	1.79	
Box No. 100	3.64	
Box No. 105	8.30	
Discharge at Malade flume	46.91	
		75.17
Loss in section		4.53
Loss per mile		.82
Percentage of loss		5.70

The average loss per mile in these two sections is approximately equal.

In the vicinity of Bear River City the slope of the country changes, and from there on the canal has a uniform grade. The loss in the third section was found to be as follows:

Losses from third section of Corinne line, June 27, 1901.

[In cubic feet per second.]

Discharge at Malade flume		55.54
Diversions:		
Box No. 130	9.97	
Box No. 135	2.16	
Discharge at bridge No. 25	40.72	
		52.85
Loss in section		2.69
Loss per mile		.72
Percentage of loss		4.84

The measurements in this section were made in the morning of June 27. The variation in the measurements at the Malade flume as given for the second and third sections was due to a change in the canal's flow during the night.

The loss in the whole length of the Corinne line upon which observations were made is given below:

Losses from upper 17.75 miles of Corinne line, June 26–27, 1901.

[In cubic feet per second.]

Discharge at Corinne division gates		118.94
Diversions:		
1st section	31.87	
2d section	28.26	
3rd section	12.13	
Discharge at bridge No. 25	40.72	
		112.98
Loss in 17.75 miles		5.96
Correction due to change in canal flow		8.63
Total loss in 17.75 miles		14.59
Total loss per mile		.82
Percentage of loss		12.27

The above tables show that the loss per mile from the Corinne line was at the time of measurement almost twice that from the west line. This may be accounted for by the fact that the west line follows the base of the hills to the west of the valley and undoubtedly receives some drainage from these hills, as already suggested, while the Corinne line follows the summit of the divide between Bear and Malade rivers, and receives no such additions. The loss from neither

line was as great as had previously been supposed. In the following table is given a summary of the results obtained on the three lines:

Summary of losses from Bear River Canal, June 25–27, 1901.

Name of line.	Length of line.	Amount entering canal.	Total loss.	Loss per mile.	Percentage of loss.
	Miles.	*Cu. ft. per sec.*	*Cu. ft. per sec.*	*Cu. ft. per sec.*	*Per cent.*
Main line	5.50	279.34	22.12	4.02	7.92
West line	15.50	138.59	6.57	.42	4.74
Corinne line	17.75	118.94	14.59	.82	12.27
Entire system	38.75	279.34	43.28	1.12	15.49

DUTY OF WATER.

While any of the crops common to the intermountain region can be grown successfully in the Bear River Valley, the principal crops grown thus far have been alfalfa and other varieties of hay, cereals, especially wheat and oats, potatoes, fruit of various kinds, and vegetables. Probably the best paying crop mentioned, considering the care and attention required in its growth, is alfalfa. The average yield of this crop is seldom less than 5 tons per acre, and many farms under the system harvest from 6 to 8 tons from the two, often three, and in some instances four crops raised each season. The yield of wheat ranges from 30 to 50 bushels per acre; that of oats, 50 to 80; and of potatoes, another staple crop of the valley, 200 to 400 bushels to the acre. Another crop which promises a great future for the valley is the sugar beet. It has been proven by repeated experiments that beets grown in this section of the State are in every way equal to those grown in Utah County, the home of Utah's beet-sugar industry. This, together with the fact that the Utah Sugar Company now owns and controls the Bear River Canal system and a large proportion of the land under it that is particularly adapted to beet culture, augurs that the day is not so far distant when the Bear River Valley will become one of the leading sugar beet producing districts of the State.

Throughout the season a record of the rainfall and evaporation was kept at a point about 2 miles west of Corinne. For the rainfall record a 10-inch rain gauge was used. The amount of evaporation from a water surface was determined by the use of a 36-inch galvanized iron tank set 26 inches in the ground and projecting 4 inches above the surface. The amount of evaporation was measured each week, after which the tank was filled to within 2 inches of the top. The rain gauge and evaporation tank were located on the bank of Lateral A 15 on the edge of a field of alfalfa, so that the conditions obtained approached very nearly those encountered in the canal channel. The results as determined are shown in the following table:

Rainfall and evaporation 2 miles west of Corinne, 1901.

Week ending—	Rainfall.	Evaporation.	Week ending—	Rainfall.	Evaporation.
	Inches.	*Inches.*		*Inches.*	*Inches.*
May 25	0.175	2.215	Aug. 31	.000	1.680
June 1	.200	1.160	Sept. 7	.000	1.680
8	.000	2.040	14	.000	1.320
15	.275	1.835	21	.000	1.320
22	.000	2.040	28	.800	1.160
29	.000	2.040	Oct. 5	1.112	1.112
July 6	.000	2.400	12	.100	.580
13	.000	2.280	19	.000	.720
20	.000	2.400	26	1.000	1.000
27	.000	1.920	Nov. 2	.900	.900
Aug. 3	.000	1.800	9	1.537	.817
10	.000	1.800			
17	.000	2.040	Total	7.862	40.142
24	1.763	1.883			

During the season of 1901 record was kept of the amount of water flowing in Bear River Canal for the purpose of determining the general duty of the water used on the irrigated lands under the system. To obtain this record a water register which gave a continuous record of the flow of the canal throughout the season, was installed on flume No. 3 in the main line, located about 2.25 miles from the head gate. During a part of the season the record was somewhat affected by the aquatic growth in the lower portion of the main line, but as the error due to this interference has been allowed for in the computations of the discharge, the following table represents, within a very small percentage of error, the amount of water delivered by the canal during the season:

Volume of water discharged by Bear River Canal, season of 1901.

Day.	May.	June.	July.	August.	September.	October.	November.
	Acre-feet.	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*
1		495.84	520.61	556.27	425.42	368.16	228.06
2		496.61	520.83	557.69	426.26	368.76	228.77
3		495.84	523.68	560.55	426.06	368.28	228.64
4	309.96	495.84	533.11	564.96	427.16	363.94	227.76
5	309.96	496.17	550.74	568.56	428.16	367.38	228.86
6	309.96	495.84	552.96	572.00	430.12	349.62	229.41
7	312.04	494.01	552.96	572.10	427.16	303.82	229.19
8	333.29	494.81	552.96	570.78	426.56	247.40	114.76
9	348.46	495.84	552.96	574.20	425.32	239.88	
10	376.90	495.62	553.85	574.31	425.10	242.32	
11	402.47	495.04	554.42	567.90	426.65	243.70	
12	422.48	495.84	555.40	555.72	428.46	243.96	
13	434.85	495.62	556.92	555.72	429.42	243.18	
14	447.76	495.30	556.92	556.02	431.14	243.51	
15	449.52	497.88	556.92	523.12	432.02	241.34	
16	451.78	496.50	557.91	510.39	432.24	238.01	
17	452.04	496.61	558.24	528.04	431.65	237.56	
18	452 81	496.61	555.17	510.86	433.61	238 67	
19	454.32	494.70	559.12	497.53	409.90	237.90	
20	454.80	496.95	559.36	499.59	388.52	237.68	
21	457.64	514.88	558.25	479.78	392.73	237.68	
22	465.60	513.36	556.42	463.46	391.08	236.17	
23	474.78	512.70	556.24	463.13	392.52	235.12	
24	472.04	518.86	557.03	462.06	391.68	234.15	
25	483.78	520.33	558.24	437.46	395.76	234.80	
26	483.96	517.64	558.02	422.80	381.18	234.80	
27	488.96	518.35	559.01	422.58	366.60	234.48	
28	483.96	514.86	557.41	422.86	365.76	232.98	
29	485.06	520.17	556.48	424.46	366.86	230.63	
30	486.60	520.83	555.48	427.76	367.51	228.75	
31	492.83		551.76	427.56		228.42	
Total	11,993.61	15,089.45	17,109.28	15,829.72	12,322.61	8,193.05	1,715.45

The figures given in the above table do not show the flow in the canal for the entire irrigation season, for the reason that water was turned into the canal about two weeks prior to the beginning of the record on May 4. As there was no means of determining the flow of the canal during this period it is not included in this report, and the following table gives the depth of water applied only for the period from May 4 to the time the water was turned out of the canal on November 8, a period of 189 days:

Duty of water under Bear River Canal, season of 1901.

Area irrigated ....acres..	17,000.000
Water used ....acre-feet..	82,253.270
Depth of water used in irrigation.....................feet..	4.838
Depth of rainfall.......................................foot..	.655
Total depth of water received by land.........feet..	5.493

Taking the above figures as a basis, it is found that during the season of 189 days the area served by each cubic foot per second of the canal's flow was 77.5 acres. This, it will be noticed, is surprisingly close to the limit named in the company's contract—1 cubic foot per second for each 80 acres. In this no account has been taken of losses from evaporation and seepage. If these be considered, the duty given above will be somewhat increased. As shown in the preceding pages, the loss from the canal approximates 15 per cent of the amount entering the head gates. A considerable portion of this loss, however, occurred in the canyon section above the water register, and consequently did not affect the results obtained. Assuming, then, that 15 per cent fairly covers all losses—a very liberal estimate when it is considered that the loss by evaporation from the canal did not exceed 0.5 per cent of the amount of water delivered—we have the depth of water received by the land decreased to 4.112 feet. This, when the rainfall is included, reaches a depth of 4.767 feet.

DUTY OF WATER UNDER LATERAL A 15.

In order to determine more accurately the duty of water under the canal, a record was kept of the amount of water applied to the land under Lateral A 15 (fig. 7), taking water from the Corinne line. This lateral supplied water to eleven small farms, varying in size from 4 to 40 acres, situated about 2 miles west of Corinne. The aggregate area served by the lateral was 208.11 acres. The crops raised on each farm were those common to the valley, and the conditions which affected their growth were in general not different from those in other sections of the valley.

The water was distributed on the time basis, each farm receiving the entire flow of the lateral a period of time in proportion to its acreage.

FLUME AND REGISTER, LATERAL A 15, BEAR RIVER CANAL.

The period of rotation used was seven days. This gave to each farmer once a week the use of the stream from forty-five to forty-eight minutes for each acre of land irrigated.

The record of the flow of the lateral was obtained by means of a measuring flume and water register placed a short distance below the head gate of the lateral and just above where the first water was used. Plate XL shows the lateral, rating flume, and water register, and on the left the rain gauge and evaporation tank by means of which

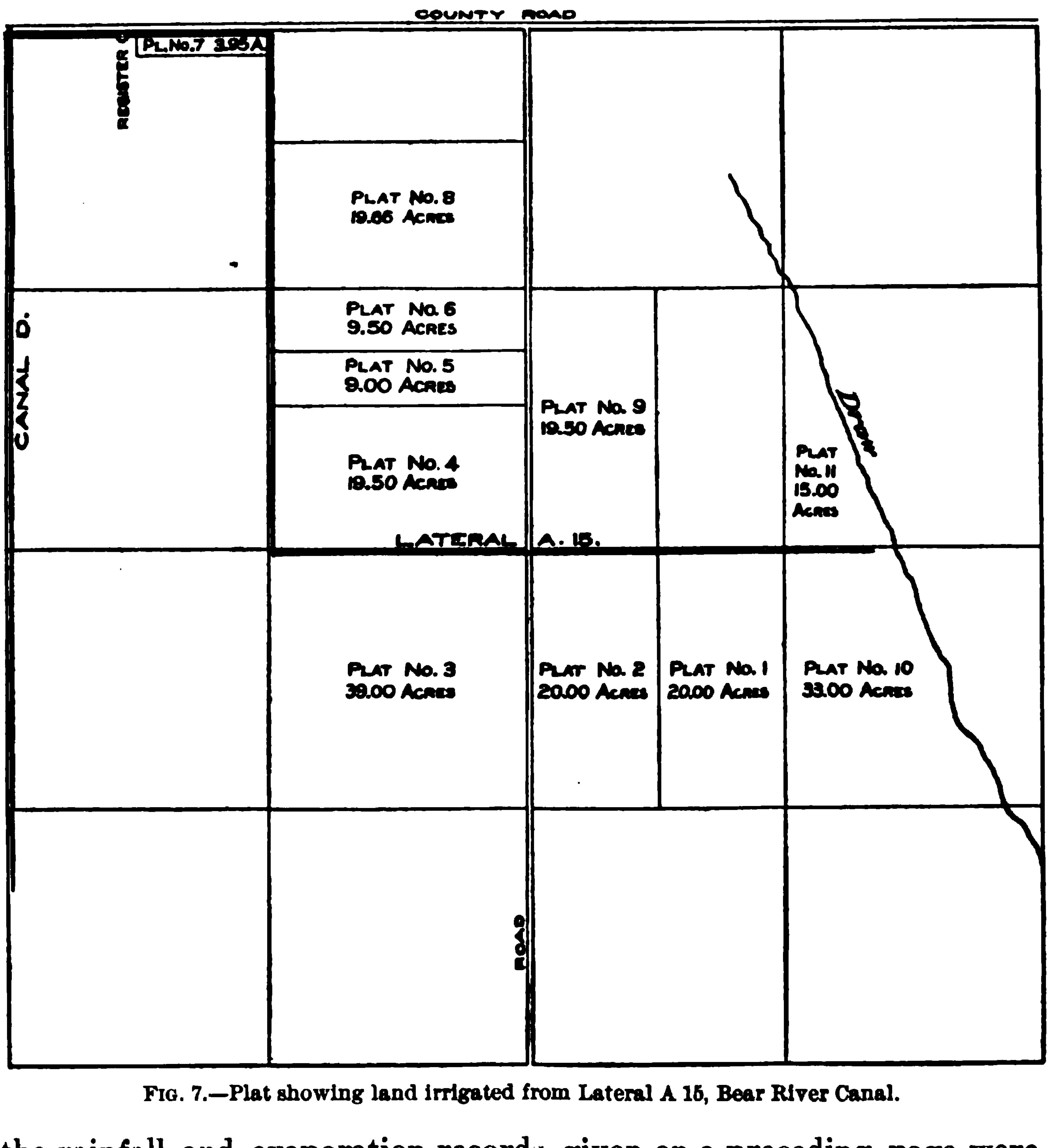


FIG. 7.—Plat showing land irrigated from Lateral A 15, Bear River Canal.

the rainfall and evaporation records given on a preceding page were obtained. The instruments used were placed in charge of Mr. H. E. Redelings, ditch rider on the Corinne line below the Red flume, who made weekly reports of the use of water under the lateral, and at the end of the season obtained the crop returns given subsequently.

Prior to the time the register was started, on May 22, there had been some irrigating done, the water having been in the canal for about three weeks. But as there was no way of determining the amount of

water that had been applied during that period, the results which follow have been based only on the amount of water applied during the period of observation, viz, May 22 to October 5, inclusive.

CROPS RAISED UNDER LATERAL A 15.

Plat 1.—The entire area of this farm was put into crops. Five acres of alfalfa yielded 25 tons, which at the current price of $5 per ton gave a gross return of $25 per acre. From 4.5 acres of wheat the yield was 21.4 bushels per acre, which at 60 cents per bushel brought $12.80 per acre. From 5 acres of oats a yield of 44.4 bushels per acre gave a gross return of $18 per acre. The remaining 5.5 acres of the farm were devoted to berries, potatoes, and cabbage. The strawberry and raspberry bushes were planted in the spring, hence these gave no return. From the potatoes and cabbage together a return of $60 was realized. The total earnings of the farm amounted to $332.60, a return of $16.63 per acre.

Plat 2.—No particulars could be had in regard to the crops raised on this farm of 20 acres. Two acres were devoted to young orchard, which yielded nothing. The remaining 18 acres was in alfalfa, which gave an average yield of 5 tons per acre, which at $5 per ton gave a gross return of $450 or $25 per acre.

Plat 3.—This plat contains 39 acres. Ten acres of this was not farmed, hence the depth of water applied was computed on the basis of 29 acres being farmed. Twenty-six acres were in alfalfa, 4 acres of which were newly planted, and from which no crop was obtained. From the 22 acres of old alfalfa a yield of 110 tons was obtained, which gave a return of $550. The remaining 3 acres was in oats, which yielded 40 bushels to the acre. The total returns from the 25 acres, from which yields were obtained, were $604, or $24.16 per acre.

Plat 4.—The entire area of this farm of 19.5 acres was in young orchard, from which no returns were realized.

Plats 5 and 6.—These plats were farmed by the same party. No particulars could be obtained as to the yield from either farm. Plat 5 was devoted to the growth of oats, plat 6 to oats and alfalfa. The entire crop on the 18.5 acres was sold for $210. This gave a return per acre of $11.35.

Plat 7.—Plat 7, containing 3.95 acres, yielded 10 tons of alfalfa from 2 acres of land, which gave a return of $50. From the remaining 1.95 acres, which were devoted to the growth of small fruits and garden vegetables, a return of $65 was realized, making the total gross earnings of the place $115, or $29.11 per acre.

Plat 8.—About 5 acres of this plat was ruined by alkali. This condition, together with the poor attention the remainder of the place received, reduced the crop yield from this 19.66 acres to a very small amount. Two acres were planted to orchard, which is not yet bearing.

From the rest of the place 20 tons of alfalfa were cut, which, at $5 per ton, gave a gross return of $100, or from the whole tract a return of $5.08 per acre.

Plat 9.—This tract of 19.5 acres was all in alfalfa. The party who farmed it received $350 for his crop, to which must be added the value of the amount fed to his team during the season, which is placed at $20. This places the gross earnings of the place at $370, and the return per acre at $18.97.

Plat 10.—Eleven acres were in young orchard, which was not allowed to bear. Fourteen acres were planted to oats and new alfalfa. From the oats a return of $150 was realized. The alfalfa was used only for pasture after the oat crop was harvested. From 1.5 acres of other alfalfa $15 was realized. The earnings from the remaining 6.5 acres, which were devoted to the growth of potatoes, cabbage, and other vegetables, amounted to $117. The gross earnings of the 22 acres from which yield was obtained amounted to $282, or $12.82 per acre.

Plat 11.—Seven acres yielded 25 tons of alfalfa, which brought $125. Seven acres of wheat produced 140 bushels, from which $84 was realized. One acre of potatoes yielded 15 bushels, for which $7.50 was received. The gross earnings from these three crops amounted to $216.50 for the 15 acres, or $14.43 per acre.

In the table which follows the results given above have been summarized and so placed that a comparison of the results obtained on the different farms may be easily made. The table also shows the quantity of water received by each plat.

Summary of crop returns and duty of water under Lateral A 15, 1901.

Plat.	Acreage.	Gross return.	Return per acre.	Water received per acre.	Return per acre-foot of water applied.
	Acres.			*Acre-feet.*	
Plat 1	20.00	$332.60	$16.63	1.718	$9.68
Plat 2	20.00	450.00	25.00	2.001	12.49
Plat 3	29.00	604.00	24.16	2.314	10.44
Plat 4	19.50	....	....	1.572	....
Plat 5	9.00	210.00	11.35	1.629	6.94
Plat 6	9.50			1.643	
Plat 7	3.95	115.00	29.11	1.928	15.10
Plat 8	19.66	100.00	5.08	2.205	2.30
Plat 9	19.50	370.00	18.97	1.750	10.84
Plat 10	33.00	282.00	12.82	1.509	8.50
Plat 11	15.00	216.50	14.43	2.000	7.22

In the column at the right of the table is shown the gross value of the crop produced by an acre-foot of water as determined from the earnings of the several farms. On account of lack of sufficient data, no attempt has been made to show the net earnings of any of the farms or the actual value of an acre-foot of water, after all expenses incurred in the growth and cultivation of the crops have been allowed for.

The average amount of water applied to the whole area under the lateral was 1.843 acre-feet per acre. If to this be added the rainfall for the season, which was 0.655 foot, the total depth of water received by the land was 2.5 feet. This it will be noticed is little more than half the depth of water applied for the entire system, which, after a 15 per cent allowance had been made for losses from the main canal by seepage and evaporation, was 4.767 feet. In the determination of the duty under the entire system no account was taken of losses from laterals and distributing ditches, neither was the matter of wasteful distribution considered at all. Under Lateral A 15 these factors were almost if not entirely eliminated, which in a large measure, no doubt, accounts for the wide variation in the results obtained.

ACKNOWLEDGMENTS.

To Mr. J. C. Wheelon, superintendent of the Bear River Canal, and to other officers of the Bear River Water Company acknowledgment is here made of the generous assistance given and of the many personal courtesies extended, by means of which it was made possible to carry on the investigations.

COLORADO.

IRRIGATION IN THE GRAND VALLEY, COLORADO, 1901.

By Arthur P. Stover,
Assistant in Irrigation Investigations.

INTRODUCTION.

Grand Valley is situated in Mesa County in the extreme western part of the State of Colorado. It derives its name from Grand River, one of the principal tributaries of Colorado River, which enters the valley from the east and, flowing in a northwesterly direction, leaves the valley at its western extremity, about 15 miles east of the boundary between Colorado and Utah. The general shape of the valley is quadrangular. Its extreme length northwest and southeast approximates 40 miles, while its greatest width does not exceed 10 or 12 miles.

The valley has been formed almost entirely by the erosive action of Grand River and its tributary, the Gunnison, which unite near the center of the valley. On all sides the valley is surrounded by high table-lands or mesas, and is protected and sheltered by the peculiar book-cliff formation so common to this section of the continent.

The irrigable land lies almost entirely on the north side of the river. On the south side there is some cultivated land along the river bottoms, but the greater part of the irrigated land on this side of the river lies on the mesas. The water used on this high land is pumped from the river. On the north side of the river the land slopes gently upward to the book cliffs which form the northern boundary of the valley. The elevation of the cultivable portions of the valley above sea level varies from 4,500 feet, along the river bottoms, to between 4,500 and 4,600 feet at the foot of these cliffs. The soil throughout the valley is of a heavy clayey formation, and varies in depth from 10 to 50 feet. On the higher levels the soil is rather sandy and in a few localities a gravelly soil is found. On these higher levels, where the drainage is good, the best fruit lands are found. Peaches, apricots, pears, plums, prunes, grapes, and cherries are grown in profusion. On the lower levels considerable fruit is also grown, but owing to the lack of natural drainage and to the soil being rather heavily impregnated with alkaline salts the success attained in its growth is not as great as upon the higher levels.

WATER SUPPLY.

It is doubtful if there is another valley in the arid regions of the same size as Grand Valley that has a more abundant or more sure water supply. From their remote mountain sources, the Grand and Gunnison rivers draw an immense supply of water, the greater part of which is as yet unused throughout the year and is carried on to the Colorado, which in turn discharges its immense volume of unused water into the Pacific Ocean. The average minimum flow[a] of Grand River, as measured during the irrigation season of 1899 just above the point at which it is joined by the Gunnison, was found to be 4,777 cubic feet of water per second. During the same period the Gunnison at its point of confluence with the Grand had an average minimum flow of 2,810 cubic feet per second. Assuming that 1 cubic foot per second will serve 50 acres, it will be seen that the minimum flow of these two rivers during the irrigation season of 1899 was sufficient to irrigate approximately 380,000 acres of land. When it is considered that all told there is not to exceed 40,000 acres of land irrigated in the valley, the immensity of the water supply may be realized.

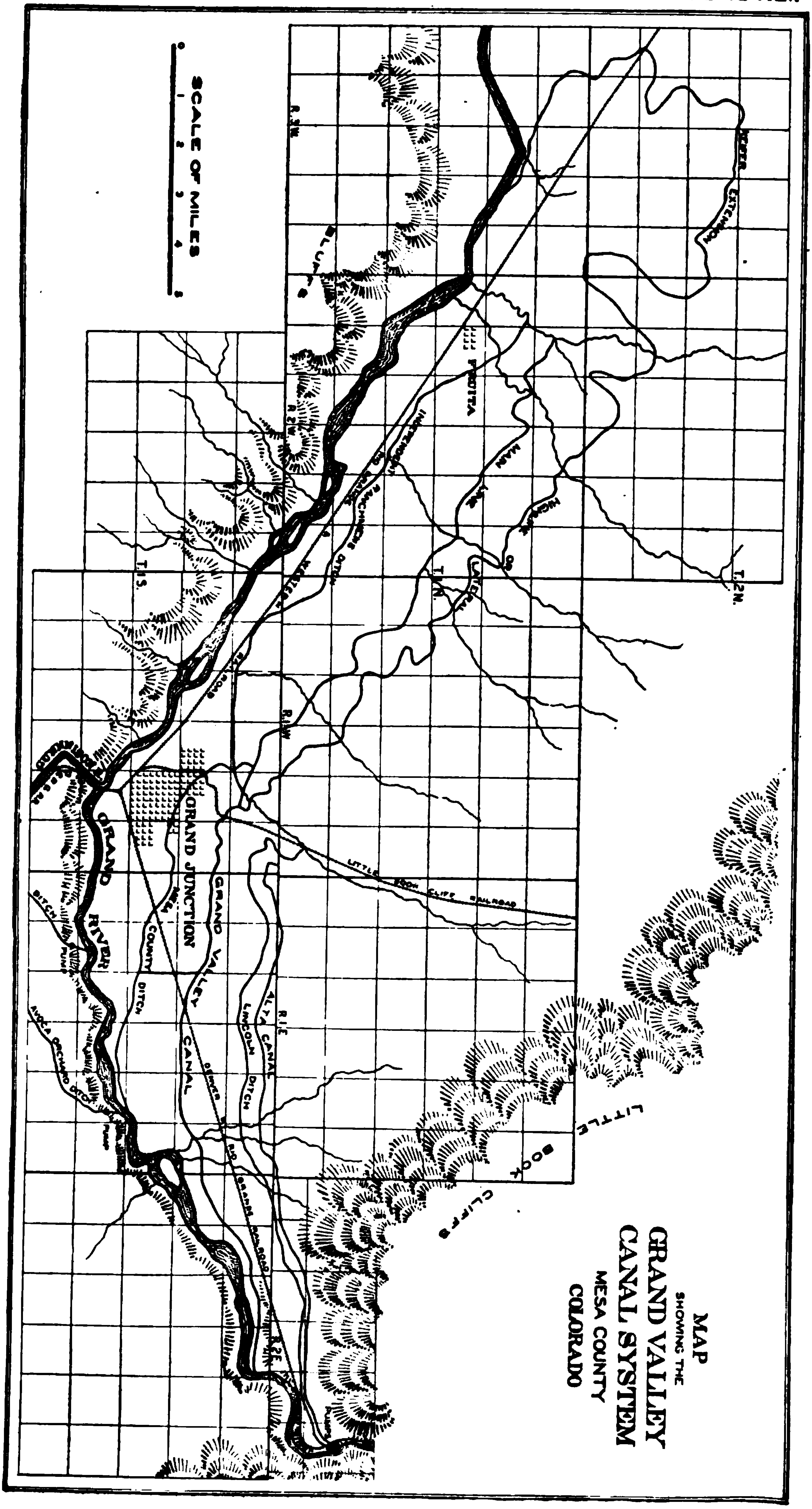
GRAND VALLEY CANAL SYSTEM.

There are a number of irrigation systems which supply water to land on both sides of the river. Of these the Grand Valley Canal and its system of distributary ditches is by far the most important. As the investigations carried on in Grand Valley during the season of 1901 were confined to this system and the irrigated land under it, nothing will be said of the other systems other than that the acreage they supply with water is comparatively small and the majority of the more important of these enterprises pump their water from the river, the peculiar formation of the valley making it exceedingly expensive to construct gravity canals for supplying the higher levels.

The Grand Valley Canal system consists of a main canal about 12 miles in length and four main distributing ditches which receive their water supply from the river through the main line. (Map, Pl. XLI.) From the main line and the four distributaries water is delivered to the irrigated land by an intricate system of feeders and laterals. The main line heads on the north side of the river at a point about 2 miles southwest of the point where the river enters the valley. From the mouth of the canyon to the head gates the river is hemmed in on its north side by high bluffs. At the head gate these bluffs bear away to the west, leaving a natural outlet for the canal line that is free from any heavy or difficult construction.

The original head gate of the canal was a timber structure. During the winter of 1900–1901 this was replaced by a most substantial masonry

[a] Colorado State Engineer's Report, 1899–1900.


MAP
SHOWING THE
GRAND VALLEY
CANAL SYSTEM
MESA COUNTY
COLORADO
SCALE OF MILES
GRAND RIVER
GRAND JUNCTION
GRAND VALLEY CANAL
ALTA CANAL
LINCOLN DITCH
COUNTY DITCH
PALISADE
MAN LINE
HIGHLINE
LATERAL
LITTLE BOOK CLIFFS
LITTLE BOOK CLIFF RAILROAD
RIO GRANDE RAILROAD
T.1 S.
T.1 N.
T.2 N.
R.1 W.
R.2 W.
R.3 W.
R.1 E.
R.2 E.

HEAD GATE OF THE GRAND CANAL.

LIFTING GEAR, HEAD GATE, GRAND CANAL.

and steel structure, at a cost of $16,000. Pls. XLII and XLIII give views of the new head gate, taken immediately after its construction. The old head gate was allowed to remain during the season of 1901 to serve as a protection to the new work until it became thoroughly settled. The head gate is set in a formation of compact sand and gravel founded on a stratum of black shale. On either side the river banks are heavily riprapped, effectively protecting them from erosion during flood seasons. The new head gate is without doubt one of the most substantial and efficient structures of its kind in the State and one of which the Grand Valley Irrigation Company may well be proud.

From the head gate the main line takes a southwesterly direction and keeps close to the river for a distance of about 5 miles. Throughout this distance the canal has an average width of 25 to 30 feet, and the depth of water carried varies from 3 to 4 feet when a full head is running. There are two overflow gates (Pl. XLIV) in the 5 miles. At the end of the fifth mile the canal crosses a dry wash in flume No. 3 (Pl. XLV). This flume is 35 feet wide and about 75 feet in length, supported on trestles and piling. These dry washes, a large number of which are crossed by the canal in its course, serve during periods of heavy rainfall as drainage channels for the large area of unoccupied land lying between the canal and the book cliffs on the north. The floods which this area yields during periods of excessive rains are enormous, and were the canal without means of taking care of the flood water by means of flumes and water bridges, serious damage would result both to the canal system and to the land dependent upon it for its water supply.

From flume No. 3 the canal flows almost due west for a distance of 3.5 miles, at which point water is delivered into what is termed the Mesa County Ditch feeder, which conveys water to the Mesa County Ditch. This ditch, at one time controlled by a separate organization, but now a part of the Grand Valley Canal system, distributes water to the district surrounding Grand Junction and the irrigated section lying along the river to the south and southeast of the town. From the point at which the Mesa County Ditch feeder is taken out the main line continues in a westerly direction, and in the tenth mile of its course the line encounters for a distance of about 2 miles what are known as the Shale Hills. In this section sidehill construction was necessary. The material through which the line runs is composed for the most part of black shale with occasionally a section of heavy clay. There is probably no section on the line that has caused so much trouble as this 2 or 2.5 miles through the Shale Hills. Several serious breaks have occurred, and the damage which resulted was large. Owing, however, to persistent work on this section, it is now in good condition, and in the future, if proper care be taken, no serious breaks or damage should occur.

About 1.5 miles north of Grand Junction, and 12 miles from the head, the canal divides into two main branches. What is termed the "high line" continues on with a uniform grade in a general northwesterly direction, while what is called "the main line" drops to a lower level and follows in a course parallel to the high line and at an average distance of 1 mile below it. A short distance below the "dividers" (Pl. LVI) what is termed the Independent Ditch feeder is taken from the main line. This feeder supplies the Independent Ranchmen's Ditch, which, like the Mesa County Ditch, prior to its coming under the control of the Grand Valley Irrigation Company, was controlled by a separate company.

The high-line canal, from the point where it leaves the main line, takes a northwesterly course and, following the general contour of the valley for a distance of 20 miles, terminates about 3 miles northwest of the settlement of Fruita. At this point water is delivered to the Kiefer Extension Ditch, which, though not under the control of the Grand Valley Irrigation Company, is dependent upon its canal system for its water supply. This extension ditch, constructed in 1898–99, furnishes water to the section located in the northwest end of the valley known locally as the "desert." This section has been under cultivation but two or three years, and its resources are, therefore, comparatively undeveloped. During the season of 1901 the extension ditch supplied water to about 2,000 acres of land, most of which was devoted to sugar beets.

On the high line, from the "dividers" to the head of the extension ditch, there are 15 flumes, 14 of which were built to span the dry washes, previously mentioned. These flumes are of simple construction and in general plan are like flume No. 3 on the main line. In the thirteenth mile of its course the high line crosses what is known as Little Salt Wash, and 5 miles below crosses the Big Salt Wash. The flumes across both these large washes are supported on trestles resting on piling. By means of waste gates in each of these flumes it is possible to regulate the flow in the canal as desired. The irrigated area under the high line, exclusive of that under the Kiefer extension, is 5,500 acres.

THE MAIN LINE.

In the first mile below the "dividers" this line loses nearly 60 feet of grade by means of two timber drops. The upper drop is built in connection with the "dividers." The water here has a vertical drop of 22 feet. From this point the line flows northwest for a distance of 0.75 mile to the "big drop." This structure is really a wooden rapid, the water being conveyed down an inclined flume. The canal above the rapid is 30 feet in width and the depth of water varies between 2 and 3 feet. By means of a tapering approach the cross section is reduced

FIG. 1.—FLUME NO. 1 AND OVERFLOW, GRAND VALLEY CANAL.

FIG. 2.—FLUME NO. 2 AND OVERFLOW, GRAND VALLEY CANAL.

FLUME NO. 3, GRAND VALLEY CANAL.

THE DIVIDERS, GRAND VALLEY CANAL.

in the inclined flume to a width of 5 feet and a depth of 4 feet. The length of the rapid is 125 feet, and in this distance the water is dropped 35 feet. At the bottom of the incline the water is discharged against a bulkhead of heavy timbers, which breaks the high velocity of the water and allows it to escape through a riffled flume 16 feet in length into the open channel. From this point the line runs parallel to the high line and at an average distance of 1 mile below it. The structures on this line are, in general, similar to those on the high line, but are far less in number. At the crossings over the larger washes arrangements similar to those on the high line are provided for the regulation of the canal's flow. The main line terminates at the Big Salt Wash, into which it discharges its surplus water. The area irrigated by this line from the head to the Big Salt Wash is 8,980 acres.

THE INDEPENDENT RANCHMEN'S DITCH.

The Independent Ranchmen's Ditch, as previously stated, derives its supply from the main line through the Independent feeder. This line also takes a northwesterly course parallel to the high line and the main line, which supply the land above it, and parallel also with the Grand River, and terminates a short distance north of Fruita. The section supplied with water through this line approximates 2,400 acres.

CANAL ORGANIZATION AND MANAGEMENT.

The canals described above were constructed within a period of four years, extending from 1882 to 1885, inclusive. The construction of the main line, extending from the head gate to the Big Salt Wash, was begun in 1882 and completed in 1884. The high line, or lateral, as it is often called, was begun in 1883. In 1884 the Independent Ranchmen's Ditch and the Mesa County Ditch were begun, and were completed in the following year. In 1886 all the interests represented by these canals were consolidated and the separate corporations controlling them were merged into what was termed the Grand River Ditch Company. At this time the control of this company passed into the hands of the Travelers' Insurance Company. In 1893 and 1894 the financial affairs of the Grand River Ditch Company became seriously involved, and in 1894 the entire holdings of the Travelers' Insurance Company, as represented by the Grand River Ditch Company, were sold to the Grand Valley Irrigation Company, which since that time has controlled and operated the entire system.

The Grand Valley Irrigation Company is purely a cooperative association composed of the farmers under the canals, each of whom owns an amount of stock in the company in proportion to the amount of water required for the irrigation of his land. The company was incorporated in January, 1894, for the purpose of purchasing the interests

of the Grand River Ditch Company, above mentioned, and also as stated in the articles of incorporation:

To furnish and distribute among the stockholders of said corporation water for irrigation and domestic purposes, but this corporation shall not be or become a common carrier of water, or make contracts to sell or rent water, or sell or rent water, or carry water for hire for irrigation or domestic use.

To use, operate, rent, sell, or otherwise dispose of any water power, or water for furnishing power or operating machinery, which said corporation may have or obtain in connection with its canals or water system.

The capital stock of the company is placed at $240,000. This is divided into 48,000 shares, at a par value of $5 per share. Each share entitles the holder to one-fourth statute inch[a] of water from the canal throughout the season. This is considered sufficient to irrigate one-half acre of land. This gives a duty of 76.8 acres per cubic foot per second. Water stock at the present time sells for about $8 an inch, or $2 per share.

The management of the canal company, and the irrigation system controlled by it, is vested in a board of nine directors, each of whom, it is prescribed in the by-laws, shall be a stockholder in the company and shall also be a resident of Mesa County. The members of the board of directors are elected annually at the regular annual meeting of the stockholders, and hold their office until their successors are elected and qualified. Any vacancies occurring in the directorate are filled by the remaining members of the board. Regular meetings of the board are held the second Saturday in January, March, May, and November of each year. Special board meetings may be called at any time upon the request of any three members of the board. The board of directors at their first regular meeting after their election elects from among their number a president and a vice-president, who hold office for one year. At the same meeting the board also appoints a secretary and treasurer, and canal superintendent, each of whom is subject to removal from office at any time. Each of these officers is required to give bonds in such sum and with such security as the directors may require, conditioned upon the faithful performance of their duties.

POWERS AND DUTIES OF BOARD OF DIRECTORS.

The board of directors has the power to make rules and regulations not inconsistent with the laws of the State of Colorado, the articles of incorporation, or the by-laws of the company, for the guidance of the officers and the management of the affairs of the company; to make assessments upon such stock of the company as shall have been issued necessary to carry out the objects and purposes of the company as

[a] The Colorado miner's inch is equivalent to a continuous flow of water of 1.56 cubic feet per minute, or 0.026 cubic foot per second. A flow of 1 cubic foot of water per second is equivalent to 38.46 Colorado miner's inches.

expressed in the articles of incorporation, and to provide the time of payment of such assessments, and the manner of collecting the same; to forfeit and sell the stock of any delinquent stockholder, or so much thereof as may be necessary to satisfy the unpaid assessments; to incur such indebtedness as they may deem necessary for carrying out the objects and purposes of the company, and to authorize the president and secretary to make the note of the company with which to raise money to pay such indebtedness.

Their duties are further defined by the by-laws, as follows:

(1) To cause to be kept a complete record of all their meetings and acts, and also the proceedings of the stockholders; present full statements at the regular annual meetings of the stockholders, showing in detail the assets and liabilities of the company, and the condition of its affairs in general. A similar statement shall be presented at any other meeting of the stockholders when thereto previously requested by persons representing at least one-third of the capital stock of the company.

(2) To supervise all the acts of the officers and employees, require the secretary and treasurer to keep full and accurate books of account, and prescribe the form and mode of keeping such books.

(3) To cause to be issued to the persons entitled thereto certificates of stock according to the several interests not exceeding in the aggregate the capital stock of the company. To allow assessments to be paid in labor when convenient to the parties concerned.

(4) To audit and adjust all bills of account against the company, and such as are allowed to direct the payment of the same.

(5) No contract by any officer of the company shall be valid without the previous authorization or the subsequent ratification of the board of directors.

DUTIES OF CANAL SUPERINTENDENT.

The superintendent appointed by the board of directors has direct management of the canal system, and, subject to the control of the board, transacts all business pertaining to the operation of the system. To aid him in his work the board appoints a number of ditch riders, whose duties consist in patrolling the canal system for the twofold purpose of detecting leaks overflows, or breaks in the canal in time to prevent serious damage, and of regulating the distribution from the main laterals to the irrigated lands.

DISTRIBUTION OF WATER.

As just mentioned, water is distributed from the main lines into the laterals by the ditch riders. A continuous flow of 1 statute inch of water is allowed for each 2 acres irrigated. Each lateral is provided with a head gate and a measuring weir. The head gate is a timber structure, so made that when the gate is locked the flow of water through it can not be increased, but, at the option of the irrigator, may be decreased or entirely stopped simply by closing the gate. The ditch rider carries the key to all head-gate locks.

Rectangular weirs are used to measure the water turned out to consumers. This means of measurement, under proper conditions, is sufficiently accurate for all practical purposes, but unless the weir is properly constructed and so located that all the conditions necessary to accurate measurement are observed the results are of little value. During the irrigation season an opportunity was afforded to examine a large number of these weirs. In a very few instances the conditions were such as to give fairly accurate results, but in a great majority of cases few, if any, of the conditions necessary to accurate measurement existed. In the use of the measuring weir the velocity with which the water flows toward the weir, known technically as the velocity of approach, should be as small as it is possible to have it. In nine-tenths of the weirs inspected the velocity of approach varied from 1 foot in some weirs to 3 and 4 feet per second in others. Another condition requisite to accurate measurement is that the depth of water behind the weir shall be at least three times the depth of the water flowing over the crest, and that the distance from the sides of the flume or box to the sides of the weir opening be at least twice the depth of water flowing over the crest. In not a single weir seen was either this bottom or side contraction complete. The bottom contraction was prevented by the deposition of silt above the weirs, and the side contraction was usually disregarded in construction. Numerous other important conditions were also disregarded, so that, taking it all in all, the results obtained from the weirs in use were widely at variance with the discharges of the laterals. In almost every case the amount being delivered was far in excess of the amount that should have been flowing in the lateral and which the weir showed to be the correct volume. The following table brings out this point quite clearly. The discharges of the laterals as shown by the weirs are compared with measurements made with a current meter.

Comparison of measured discharges of laterals with discharges shown by measuring weirs (measured June 9–12, 1901).

Lateral.	Measured by weir.		Measured by meter.	
	Cu. ft. per sec.	*Miner's inches.*	*Cu. ft. per sec.*	*Miner's inches.*
No. 55 M. L	1.978	76.07	2.488	95.70
No. 85 M. L	.541	20.81	.569	21.88
No. 120 M. L	1.718	66.07	1.925	74.04
No. 135 M. L	2.615	100.58	3.812	146.60
No. 205 M. L	.817	31.42	1.053	40.50
No. 230 M. L	1.858	71.42	3.280	126.10
No. 260 M. L	2.415	92.88	3.538	136.10

The table shows that in some laterals over 40 per cent more water was being delivered than was being paid for according to schedule. This feature is one which should receive the attention of the canal authorities as well as the irrigators, for in justice to all the stockholders in the canal no one should receive any more or any less water than the amount to which he is entitled.

REVENUES.

To provide means for paying the interest on the bonded indebtedness of the company, and for the maintenance and operation of the canal system, an annual assessment is levied upon all outstanding capital stock of the company. This assessment varies with different years, according to the amount of expense incurred. The object is to furnish water to the stockholders at the actual cost of its delivery. In cases of emergency, when the annual assessment proves to be insufficient to meet the requirements of the company the board of directors has the power to levy an additional assessment upon the stockholders sufficient to cover such deficiency in the revenues.

If, after having been given due notice of any assessment, any stockholder fails to pay the assessment levied upon stock possessed by him, the board of directors may enforce the collection of such assessment in any one or all of the following three methods:

First. By refusing to deliver water to such stockholder until his assessment has been fully paid.

Second. By bringing suit against such stockholder to recover the amount of assessment levied.

Third. By selling at public auction sufficient of the stock of stockholder so in default to cover the amount of his delinquency. If this latter course is adopted the sale of stock must be advertised according to law.

In the following summary the annual assessments for the past five years are given:

Summary of annual assessments, 1897–1901.

Year.	Assessment.		Year.	Assessment.	
	Per inch of water.	Per acre.		Per inch of water.	Per acre.
1897	$1.28	$0.64	1900	$0.96	$0.48
1898	1.60	.80	1901	2.08	1.04
1899	.96	.48			

During 1896 heavy storms caused breaks and washouts along the canal line. The repairing of these damages necessitated the large assessments levied in 1897 and 1898. The high assessment of 1901 was due to the extensive improvements made in various parts of the system. New flumes and other structures were built at a cost of $7,719.74, an expenditure of $15,815.20 was made for the new head gate previously referred to, $1,046.30 went for work in the river and canal channel above and below the new head gate, and $6,108.55 was spent in enlarging and cleaning the high line in order that the Kiefer Extension Ditch might be supplied with an increased amount of water. These expenditures made in all a total of $30,689.79 spent in the permanent improvement of the canal system.

SEEPAGE INVESTIGATIONS.

A subject of vital importance to the irrigators of Grand Valley, and one which demands the attention of all those dependent upon agriculture in this region, is that of the serious, not to say disastrous, results caused by seepage waters and imperfect drainage. Owing to the peculiar geological structure of the valley, the drainage of the greater part of the irrigated section is poor. In many places the dip of the substrata is from rather than toward the river, the natural outlet for drainage. The soil and subsoil are heavy and tend to retain moisture and become saturated. This condition, together with the soil being heavily impregnated with alkaline salts, makes artificial drainage necessary before the lands can be successfully farmed. On the higher lands of the valley the effects of ground water are not so apparent. In these sections the soil is more porous, giving better drainage and a consequent freedom from the evil effects of alkali.

This report deals with the seepage question only as related to losses from canals. A series of seepage measurements was made July 9 to 12, inclusive. The section of the system on which these measurements were made included the main line between flume No. 3 and the "dividers," and the entire length of the high line from flume No. 1 just below the "dividers" to the point at which water is delivered to the Kiefer Extension Ditch. The aggregate length of the canal line covered by these investigations was 30 miles. The canals were taken up by sections, varying in length from 1 to 6 miles, and the loss from each section was determined separately. To determine this loss, it was necessary to know the inflow at the upper end of the section and the total outflow from the section, which included the aggregate amount diverted by laterals and feeders and the outflow at the end of the section. The difference between the outflow and the inflow, of course, represented the net gain or loss in the section. The losses from the canal occur in two ways: By seepage, which may be made to include leakage and waste; and evaporation. In the following results the loss by evaporation has been ignored for the reason that the period of time elapsing between the measurements at the upper and lower ends of any section in no case exceeded three or four hours and the amount of evaporation from the canal surface during this period would be more than counterbalanced by the inaccuracies of measurement.

MEASUREMENTS OF THE MAIN LINE, FROM FLUME NO. 3 TO THE "DIVIDERS."

The portion of the main line on which measurements were made was divided into two sections. The first extended from flume No. 3 to James footbridge, a distance of 4.75 miles. The other extended from James footbridge to a wagon bridge just above the "dividers,"

covering a distance of 2.25 miles, and embracing the section of the line which traverses the Shale Hills previously mentioned.

In the first section the canal channel is entirely in earth, the formation being a heavy, firm clay. In this section there are 32 laterals taken from the canal. On the day the measurements were taken all these but one were drawing water. In addition to the supply drawn by the laterals the Mesa County Ditch feeder was drawing 56.12 cubic feet per second. The results of the measurements made are given in the following table:

Measurements in first section of main line July 9, 1901.

[In cubic feet per second.]

Discharge at flume No. 3		336.974
Diversions:		
Lateral No. 55	2.488	
Lateral No. 60	.100	
Lateral No. 65	.250	
Lateral No. 70	1.443	
Lateral No. 73	.104	
Lateral No. 75	1.217	
Lateral No. 77	.513	
Lateral No. 80	.171	
Lateral No. 85	.569	
Lateral No. 90	1.706	
Lateral No. 95	.393	
Lateral No. 100	.808	
Lateral No. 105	.913	
Lateral No. 110	1.667	
Lateral No. 115	.488	
Mesa County Ditch feeder	56.119	
Lateral No. 120	1.925	
Lateral No. 125	1.294	
Lateral No. 130	1.651	
Lateral No. 135	3.812	
Lateral No. 140	.130	
Lateral No. 145	.886	
Lateral No. 155	.464	
Lateral No. 160	3.673	
Lateral No. 165	.772	
Lateral No. 170	1.084	
Lateral No. 175	.226	
Lateral No. 180	.130	
Lateral No. 185	.039	
Lateral No. 195	.552	
Lateral No. 200	.514	
Discharge at James footbridge	260.472	
		346.573
Gain in section		9.599
Gain per mile		2.021
Percentage of gain		2.848

This first section is the only section in the entire system on which measurements were made which showed a gain in the canal's flow. It is very likely that a portion of this increase came from the irrigated lands lying to the west of Palisade, which section derives its water supply from small canals that are supplied from the river by pumps located a short distance east of Palisade. But whether the entire gain shown is due to this seepage water entering the canal or to some slight error in measurement is a matter of conjecture, and must be left to future investigation.

The second section of the main line, as stated above, encounters the Shale Hills lying north of Grand Junction. In this section it was expected that the loss would be considerable, for at numerous places along the canal small trickling streams could be seen issuing from the canal bank, which, after flowing a short distance on the surface would lose themselves in swampy and marshy places, evidently the results of such leakage. The loss in the second section is shown in the following table:

Measurements in second section of main line, July 10, 1901.

[In cubic feet per second.]

Discharge at James footbridge		260.472
Diversions:		
Lateral No. 205	1.053	
Lateral No. 210	.130	
Lateral No. 215	.449	
Lateral No. 220	1.040	
Lateral No. 225	.078	
Lateral No. 230	3.280	
Lateral No. 235	1.026	
Wellington Wheel	.458	
Lateral No. 240	.182	
Lateral No. 245	2.659	
Lateral No. 250	.234	
Lateral No. 255	.748	
Discharge at "dividers"	240.439	
		251.776
Loss in section		8.696
Loss per mile		3.865
Percentage of loss		3.340

In the following table is given a summary of the results of the seepage measurements made on the two sections of the main line just considered:

Summary of measurements on main line, July 9–10, 1901.

[In cubic feet per second.]

Discharge at flume No. 3		336.974
Diversions	97.438	
Discharge at "dividers"	240.439	
		337.877
Gain in 7 miles		.903

These figures, on the assumption that no errors were made in the measurement of the first section, would indicate that the loss in the 2.25 miles of the line through the Shale Hills was more than compensated by the gain in the 4.75-mile section immediately above, and that, taken as a whole, the main line below flume No. 3 received from the irrigated land above an amount of water practically equal to all the losses from the canal channel, both by seepage and evaporation.

LOSSES FROM HIGH LINE FROM THE "DIVIDERS" TO HEAD OF KIEFER EXTENSION DITCH.

The high line was divided into five sections, and in each the losses by seepage were determined separately. The first section extended from flume No. 1, situated a short distance below the "dividers," to the wagon bridge at Henderson's place, and covered a distance of 5 miles. In this section of the canal there is considerable sidehill work, and the consequent loss by seepage is considerable. The water section of the canal is entirely in excavation, however, so that loss through porous banks is reduced to a minimum.

Measurements in first section of high line, July 10, 1901.

[In cubic feet per second.]

Discharge at flume No. 1		139.616
Diversions:		
Waste at flume No. 1	1.834	
Lateral No. 15	2.150	
Lateral No. 20	.065	
Lateral No. 25	.553	
Lateral No. 40	1.653	
Lateral No. 45	.156	
Lateral No. 50	.091	
Lateral No. 55	1.477	
Lateral No. 60	1.581	
Waste at flume No. 2	.584	
Laterals Nos. 65 and 70	1.530	
Lateral No. 75	.104	
Lateral No. 80	.696	
Lateral No. 85	1.333	
Waste at flume No. 3	.078	
Lateral No. 90	.848	
Lateral No. 100	.065	
Lateral No. 105	1.565	
Lateral No. 110	.501	
Lateral No. 115	.449	
Lateral No. 120	.267	
Lateral No. 125	.510	
Discharge at Henderson's Bridge	116.474	
		134.564
Loss in section		5.052
Loss per mile		1.010
Percentage of loss		3.620

The second section of the high line extended from Henderson's Bridge to flume No. 6, covering a distance of 1.25 miles. The conditions which affect seepage in this section of the line are very similar to those encountered in the first section, the greater length of the section being sidehill construction. The diversions made from the canal are numerous, but at the time of measurement were small in amount. The results of the measurements follow:

Measurements in second section of high line, July 10, 1901.

[In cubic feet per second.]

Discharge at Henderson's Bridge		116.474
Diversions:		
Lateral No. 135	0.138	
Lateral No. 140	.631	
Lateral No. 145	.214	
Lateral No. 150	.924	
Lateral No. 155	.513	
Blind box	.426	
Lateral No. 160	.462	
Lateral No. 165	.317	
Lateral No. 170	.040	
Lateral No. 180	.437	
Lateral No. 185	.209	
Lateral No. 190	.130	
Lateral No. 195	1.834	
Lateral No. 200	.945	
Lateral No. 210	.714	
Lateral No. 220	.620	
Discharge at flume No. 6	106.981	
		115.535
Loss in section		.939
Loss per mile		.751
Percentage of loss		.810

In the third section of the high line, extending from flume No. 6 to Hartman's Bridge, and covering a distance of 6.75 miles, the line traverses a more level section of country, and in this section the loss by seepage is reduced to a very small percentage of the amount carried.

Measurements in third section of high line, July 11, 1901.

[In cubic feet per second.]

Discharge at flume No. 6		106.981
Diversions:		
Lateral No. 225	0.615	
Lateral No. 230	.942	
Lateral No. 235	.537	
Feeder at Pritchard's place	5.250	
Lateral No. 255	.958	
Lateral No. 260	.851	
Lateral No. 265	.796	

Diversions—Continued.

Lateral No. 270	0.706	
Lateral No. 275	.254	
Lateral No. 280	2.622	
Lateral No. 285	.052	
Lateral No. 290	1.263	
Lateral No. 300	1.934	
Lateral No. 305	1.053	
Lateral No. 310	3.595	
Lateral No. 315	.798	
Lateral No. 320	4.875	
Lateral No. 325	1.529	
Lateral No. 330	4.284	
Lateral No. 335	1.050	
Lateral No. 340	.134	
Lateral No. 350	.071	
Lateral No. 355	.143	
Discharge at Hartman's Bridge	71.185	
		105.497
Loss in section		1.484
Loss per mile		.220
Percentage of loss		1.380

The fourth section covered a distance of 4.75 miles, and extended from the wagon bridge near Hartman's to flume No. 14, which spans the Big Salt Wash. This section, like the third section, also traverses a comparatively level country for the greater part of its length. There is some sidehill construction in this section of the line, but this portion of the canal is in excellent condition and the loss by seepage is very small in comparison with other sidehill sections of the canal. In this section the canal crosses both Little Salt Wash and Big Salt Wash, and also one or two minor drainage channels.

Measurements in fourth section of high line, July 12, 1901.

[In cubic feet per second.]

Discharge at Hartman's Bridge		79.629
Diversions:		
Lateral No. 360	1.376	
Lateral No. 365	.052	
Lateral No. 370	2.104	
Lateral No. 375	.386	
Lateral No. 380	.026	
Lateral No. 385	1.666	
Lateral No. 390	.026	
Lateral No. 395	.360	
Lateral No. 400	3.246	
Lateral No. 410	3.619	
Lateral No. 415	1.517	
Lateral No. 420	.639	
Lateral No. 425	.481	

Diversions—Continued.		
Lateral No. 435	0.909	
Lateral No. 440	.330	
Lateral No. 445	.831	
Lateral No. 450	1.961	
Lateral No. 455	.866	
Lateral No. 460	.071	
Lateral No. 465	.353	
Discharge at flume No. 14	55.912	
		76.731
Loss in section		2.898
Loss per mile		.610
Percentage of loss		3.640

In the fifth section, from flume No. 14 to the rating flume (flume No. 15) at the end of the high line and head of the Kiefer Extension Ditch, the loss from the canal channel was very small, being less per mile than any other section of the high line except the third. The length of this section is 3.5 miles.

Measurements in fifth section of high line, July 12, 1901.

[In cubic feet per second.]

Discharge at flume No. 14		55.912
Diversions:		
Leakage from flume No. 14	0.104	
Lateral No. 470	.528	
Lateral No. 480	1.139	
Lateral No. 485	.035	
Lateral No. 490	.845	
Lateral No. 495	4.933	
Lateral No. 505	.677	
Lateral No. 515	1.209	
Lateral No. 520	.592	
Lateral No. 525	.297	
Lateral No. 530	.705	
Lateral No. 535	.374	
Lateral No. 540	.783	
Lateral No. 545	.195	
Discharge at flume No. 15	42.509	
		54.925
Loss in section		.987
Loss per mile		.282
Percentage of loss		1.770

In the following table have been summarized the results of the measurements on the high line showing the loss in the 21.25 miles of the line studied:

Summary of measurements in high line July 10-12, 1901.

[In cubic feet per second.]

Discharge at flume No. 1		139.616
Diversions:		
First section	18.090	
Second section	8.554	
Third section	34.312	
Fourth section	20.819	
Fifth section	12.416	
Discharge at Kiefer extension rating flume	42.509	
		136.700
		2.916
Correction due to change in flow of canal		8.444
Total loss		11.360
Loss per mile		.534
Percentage of loss		8.140

Although the loss as shown is not excessive, yet, in consideration of the fact that the Grand Valley soil has a strong tendency to become seepy and alkaline when an excess of water is applied, steps should be taken to prevent any seepage from the canal, both to avert the damaging of valuable land and to increase the amount of water supplied by the canal.

DUTY OF WATER.

The soil and climatic conditions of Grand Valley are such that any of the crops common to the temperate zone can with little difficulty be raised successfully. The leading crops of the valley, however, are, in order of importance, fruit, alfalfa, sugar beets, grain and vegetables. Many thousand acres have been planted in orchards and vineyards representing all kinds of fruits. The majority of these orchards are as yet young and have not come into full bearing. Many, however, are in their prime, and their productions, in point of quality as well as quantity, would be hard to excel. The "Grand Junction peach," known throughout the West, is an illustration of what can be produced in this valley in the line of fruit.

From reports from several thrifty farmers and fruit growers of the valley it was found that returns from orchards varied from $100 to $200 per acre, according to the nature of the crop. Three good crops of alfalfa can be cut each season and a stand of 8 to 10 inches had for pasturage. The average yield per acre varies between 4 and 6 tons, which, at current prices during 1901, gave a return per acre of from $20 to $35. Alfalfa on the average is irrigated twice for each crop, or receives from five to seven waterings each season. Comparatively little grain is grown in the valley, there being more money in raising alfalfa at its present price.

The other crop, which promises to become of much importance to Grand Valley, is the sugar beet. This crop, with proper care and attention, can be raised successfully and profitably. The Colorado Beet Sugar Factory, having a capacity of 350 tons of beets daily, is located at Grand Junction, within easy reach of all parts of the valley, assuring to the farmers a ready market for all the beets they can produce. The average yield of beets for the valley so far has been between 7 and 8 tons per acre. Good yields average 10 tons, while the best range from 20 to 22 tons to the acre. The reason for this small tonnage lies in the fact that thus far the majority of the farmers have had little confidence in beets, and fields that have received good attention and have produced well are the exception rather than the rule. Another reason is the nature of the land on which the beets are grown. The soil being a heavy clay, and its drainage being poor, the surface is liable to bake, especially when the seed is first planted, seriously retarding the growth of the young plants. Alkali is also a factor which demands consideration. While beets can stand considerable alkali and apparently flourish, those grown on this class of soil contain a high percentage of alkaline matter, which materially decreases their sugar-producing value.

During the irrigation season of 1901 an accurate record was kept of the amount of water flowing in the main canal and also of the water delivered to the Kiefer Extension Ditch. The record of the flow in the main line was kept by means of a water register installed on flume No. 3 (Pl. XLV). This instrument gave a continuous record of the depth of water flowing through the flume, from which record the flow of the canal for the season was determined. The rating flume on the Kiefer Extension Ditch was located at the terminus of the high line, about 3 miles northwest of Fruita. This flume was in excellent condition for measuring purposes, having been constructed during the early spring of 1901. The register with which the record on this flume was kept failed to work satisfactorily during part of the season, and during the latter part of October it failed to record at all. The flow during this period has been approximated from that in the main line during the same period, so that the table, as given below, shows the record complete for the same period as that of the record of flow of the main line, viz, May 7 to October 31, inclusive, or one hundred and seventy-eight days. Owing to an unavoidable delay in getting the season's observations started, the records obtained do not cover the entire irrigation season, the water having been first turned into the canal about April 20.

In the two following tables are given the results obtained at flume No. 3 on the main line and the Kiefer Extension rating flume:

Discharge of Grand Valley Canal, May 8 to October 31, 1901.

Day.	May.	June.	July.	August.	September.	October.
	Acre-feet.	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*
1	....	625.18	653.92	576.28	330.78	465.48
2	....	624.43	661.97	570.25	332.28	465.45
3	....	623.93	663.48	576.32	332.28	465.48
4	....	622.14	669.29	576.57	332.28	460.11
5	....	576.79	670.04	578.57	340.85	449.53
6	....	584.07	666.25	565.94	370.64	429.12
7	....	579.05	659.67	477.47	373.14	421.32
8	136.88	562.58	659.17	374.40	373.64	443.99
9	473.27	560.44	658.67	102.44	374.64	450.27
10	488.60	558.65	653.90	23.50	374.64	446.78
11	501.20	545.83	638.28	0.00	380.42	418.02
12	506.72	541.99	655.92	345.04	394.79	407.43
13	530.42	536.96	656.67	524.87	402.13	393.01
14	537.96	529.65	655.92	533.96	409.13	392.76
15	552.61	509.50	653.40	537.96	405.38	402.34
16	578.55	533.21	636.77	536.46	406.30	409.38
17	589.14	524.59	629.43	541.27	449.56	405.38
18	599.95	516.53	627.93	524.87	457.36	397.06
19	597.44	555.62	629.43	469.64	457.86	391.75
20	600.96	558.14	628.98	441.98	456.36	368.60
21	608.06	578.82	621.68	483.60	458.36	362.77
22	611.81	592.20	620.37	488.60	457.86	358.02
23	610.56	611.57	617.39	500.66	454.61	356.52
24	610.56	621.68	603.00	503.19	455.86	356.52
25	615.60	618.62	610.56	500.42	460.61	356.52
26	625.43	630.72	610.56	497.10	457.86	355.02
27	624.18	649.12	610.56	494.35	456.86	353.99
28	624.93	646.58	610.06	491.85	466.47	355.02
29	625.18	647.29	607.56	482.85	464.68	353.00
30	624.68	646.56	591.41	444.74	464.44	353.77
31	623.68	....	578.81	356.75	....	353.52
Total	13,498.37	17,502.44	19,711.05	14,121.90	12,352.07	12,397.93

Discharge of Kiefer Extension Ditch, season 1901.

Day.	May.	June.	July.	August.	September.	October.
	Acre-feet.	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*
1	....	63.03	69.56	53.46	60.28	61.87
2	....	58.60	67.95	50.38	62.30	60.77
3	....	51.72	67.55	49.94	62.30	60.96
4	....	80.62	77.26	74.93	62.30	63.39
5	....	92.53	78.51	73.77	62.30	56.21
6	....	80.50	78.30	67.60	57.80	60.78
7	9.21	82.30	76.97	53.46	59.10	64.27
8	53.66	80.54	81.29	22.76	59.10	60.78
9	52.48	81.72	82.31	0.00	60.28	56.21
10	51.53	80.75	84.60	0.00	61.30	56.21
11	50.00	80.52	83.85	0.00	62.30	60.76
12	52.50	81.19	82.58	0.00	62.30	60.76
13	55.75	76.61	83.48	40.56	64.27	64.27
14	48.17	76.18	84.97	65.96	64.27	64.27
15	50.99	71.78	82.84	62.63	64.27	64.27
16	45.98	73.87	83.49	60.28	60.76	62.30
17	60.70	76.98	83.69	61.62	56.21	62.30
18	65.02	68.47	84.08	69.54	56.05	62.30
19	66.87	67.70	83.41	67.95	55.17	60.78
20	67.51	68.11	84.34	65.88	54.95	56.05
21	63.31	61.77	59.49	66.93	54.33	56.05
22	59.99	45.34	30.88	67.47	54.32	56.05
23	57.85	63.48	71.11	66.55	51.21	54.32
24	56.02	67.80	66.61	62.31	52.27	54.32
25	57.48	65.60	72.69	70.26	59.87	51.21
26	62.98	67.48	21.60	69.31	55.30	51.21
27	63.03	66.62	40.20	54.80	52.35	51.21
28	20.57	70.21	50.38	68.40	49.39	46.00
29	35.80	70.07	58.20	67.59	56.87	46.00
30	56.02	69.57	60.10	65.99	58.51	40.20
31	60.70	....	59.25	65.99	....	40.20
Total	1,324.12	2,141.66	2,191.54	1,666.32	1,752.03	1,766.28

EVAPORATION AND RAINFALL.

The rainfall was determined by the use of a 10-inch standard rain gauge set about 4 feet above the surface of the ground. The amount of evaporation was measured from the water surface in a 30-inch by 36-inch galvanized iron tank set 26 inches in the ground. Readings were taken once a week, after which the amount of water evaporated from the tank was replaced, the surface of the water being raised to within 3 inches of the top of the tank. The evaporation tank and rain gauge were located near the "dividers" where the high line is taken from the main line. The rainfall and evaporation record and also the record of the flow at flume No. 3 were taken by Mr. M. J. Sullivan, care taker of the head gate and main line of the canal system. The record of flow at the Kiefer Extension rating flume was kept by Mr. G. E. Barton, ditch rider on the lower section of the high line.

Rainfall and evaporation, Grand Valley, Colo., 1901.

Week ending—	Rainfall.	Evaporation.	Week ending—	Rainfall.	Evaporation.
	Inches.	*Inches.*		*Inches.*	*Inches.*
May 11	0.00	0.44	August 17	0.23	1.67
May 18	.32	1.57	August 24	.73	1.04
May 25	.00	1.69	August 31	.92	1.04
June 1	.23	2.36	September 7	.00	1.56
June 8	.80	2.99	September 14	.00	1.25
June 15	.38	1.69	September 21	.00	1.19
June 22	.00	1.75	September 28	.00	1.44
June 29	.00	2.31	October 5	.00	1.31
July 6	.00	1.94	October 12	.45	.89
July 13	.38	1.76	October 19	.00	.80
July 20	.00	2.06	October 26	.00	.56
July 27	.00	1.94	November 2	.06	.56
August 3	.00	1.94			
August 10	.82	1.57	Total	5.32	39.32

DUTY OF WATER UNDER ENTIRE SYSTEM.

During the irrigation season of 1901 there were 21,800 acres of land irrigated under the Grand Valley Canal system. This area includes that irrigated under the Kiefer extension, aggregating 2,000 acres, but not the area irrigated from the main line above flume No. 3 where the record of flow was taken, which area approximated 150 acres. The duty of the water is given in the following summary:

Duty of water under Grand Valley Canal, 1901.

Area irrigated ....acres..	21,800.000
Water used ....acre-feet..	89,583.760
Depth of water used in irrigation..........feet..	4.109
Depth of rainfall ....foot..	.443
Total depth of water received by land..........feet..	4.552

The average flow for the season of the main line at flume No. 3 was 255.17 cubic feet per second, or 9,813.8 statute inches. This gives a duty of 85.4 acres per cubic foot per second, or 2.22 acres per statute inch.

DUTY OF WATER UNDER KIEFER EXTENSION DITCH.

The total area irrigated under this part of the system approximated 2,000 acres. Of this area the major portion was new land recently brought under cultivation, which naturally required more water than did the sections which had been cultivated for some years. Almost the entire area was devoted to sugar beets. The following table shows the duty of the water in this section of the valley:

Duty of water under Kiefer Extension Ditch, 1901.

Area irrigated ....acres..	2,000.000
Water used ....acre-feet..	10,841.950
Depth of water used in irrigation ....feet..	5.421
Depth of rainfall ....foot..	.443
Total depth of water received by land........feet..	5.864

The area served per cubic foot per second is 64.71 acres, or 1.68 acres per statute inch.

The average flow at the rating flume for the season was 30.90 cubic feet per second, or 1,188.4 inches. The Grand Valley Canal Company agreed to furnish the Kiefer Extension Ditch 1,000 to 1,400 inches of water. The above figures show that the company fulfilled its contract.

At the end of the irrigation season inquiries were sent out to all the irrigators under the canal for the purpose of obtaining statements regarding crop yields, methods of irrigation, nature of water service rendered by the canal system, whether to produce the best results the amount of water used should be increased or decreased, remedies for damage done by alkali, etc.

The figures given in the fore part of the discussion relative to yields and returns from the principal crops were obtained from these crop reports. The answers to the questions further showed:

(1) That furrow irrigation was used for all crops. This is necessary in order to prevent the soil baking, which it would do if flooded. With such crops as alfalfa, where the ground is shaded, flooding may be practiced without serious damage, as the soil, being shaded, is less likely to have a crust formed on its surface.

(2) That the system of measurement used in distributing the water from the canal system was satisfactory, that the amount of water supplied by the canal was about the same as that of former years, and that the service rendered by the canal was also in every way satisfactory.

(3) That the consensus of opinion seemed to be that the amount of water used for irrigation was in excess of the needs of the crops and that in general the amount used should be decreased.

(4) That the farmers generally, especially those owning land in the bottom of the valley, are troubled with alkali, most of them attributing its presence to the soil being heavily impregnated with alkaline salts, the excessive use of water, and poor drainage. As remedies, the following were given: Restricted use of water, cultivation of surface, and subsurface drainage.

SUMMARY.

The results of the investigations in Grand Valley during the season of 1901 seem to warrant the following conclusions and recommendations:

(1) The question of importance to the Grand Valley farmer is not how to provide against a scarcity of water, but rather how to avoid the evil effect of an abundant water supply.

(2) The alkalinity of the soil is a factor which demands the utmost care and attention on the part of the irrigator that his crops may not be damaged by its effects.

(3) Taking the valley as a whole, too much water is used for irrigation. Irrigate in time but not too often.

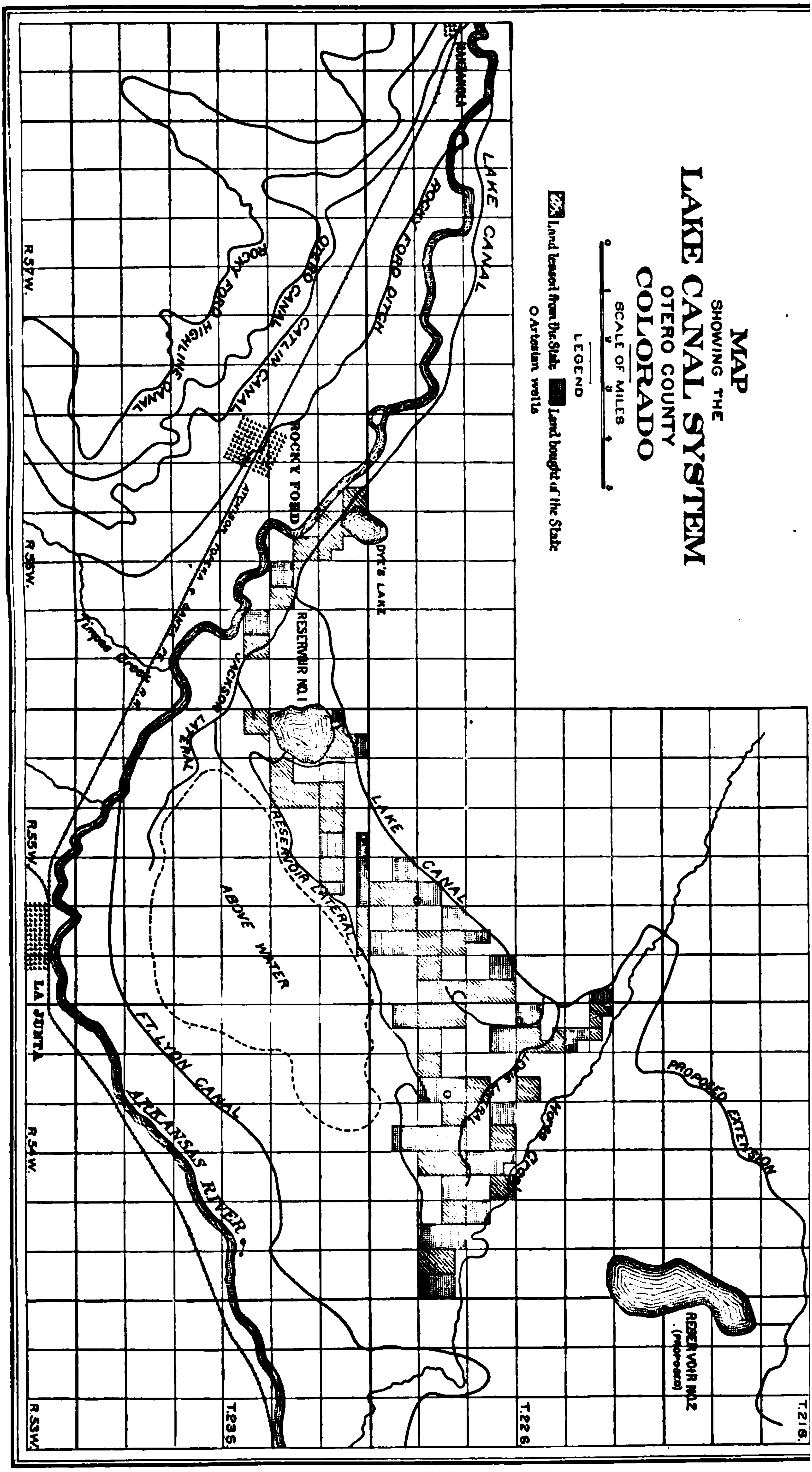
(4) Systematic and thorough drainage should be practiced in order to improve the condition of the soil and prevent damage from alkali.

(5) No water should be allowed to run to waste. Use the waste when practicable; when this can not be done convey it to some natural drainage channel rather than allow it to saturate and damage lands below.

(6) Too much reliance should not be placed on water alone to raise crops. In connection with it, practice crop rotation; plow under manure, beet tops, alfalfa, or clover; and above all, practice thorough and timely cultivation.

ACKNOWLEDGMENTS.

Acknowledgment is hereby made to Mr. J. S. O'Neil, superintendent of Grand Valley Canal, and to other officers of the canal company, who in various ways assisted in the investigation and furnished valuable data relative to Grand Valley and the Grand Valley Canal system. Acknowledgment is also here made of the courtesies extended by the Colorado Sugar Manufacturing Company and the Colorado Midland Railroad.


MAP
SHOWING THE
LAKE CANAL SYSTEM
OTERO COUNTY
COLORADO
SCALE OF MILES
LEGEND
Land leased from the State
Land bought of the State
O Artesian wells
MANZANOLA
LAKE CANAL
ROCKY FORD DITCH
OTERO CANAL
CATLIN CANAL
ROCKY FORD HIGHLINE CANAL
ROCKY FORD
DYE'S LAKE
RESERVOIR NO. 1
JACKSON LATERAL
RESERVOIR LATERAL
ABOVE WATER
Timpas Creek
FT. LYON CANAL
ARKANSAS RIVER
LA JUNTA
Horse Creek
PROPOSED EXTENSION
RESERVOIR NO. 2 (PROPOSED)
R.57W.
R.56W.
R.55W.
R.54W.
R.53W.
T.23S.
T.22S.
T.21S.

IRRIGATION IN THE ARKANSAS VALLEY, COLORADO.

By Arthur P. Stover,

Assistant in Irrigation Investigations.

INTRODUCTION.

The Arkansas Valley, which embraces the major portion of Pueblo, Otero, Bent, Prowers, and Kiowa counties, in the southeastern part of the State, comprises the largest body of agricultural land in Colorado. The Arkansas River, from which the irrigated land in this section derives its water supply, rises in Lake County, in the west central part of the State. Flowing thence in a general southeasterly direction, it traverses the valley in a winding course and enters the State of Kansas near the center of the eastern boundary of Prowers County.

The soil on the first bottoms of the Arkansas Valley is a rich, alluvial deposit, while that of the higher levels is generally a deep sandy loam. The surface of the valley lands is quite smooth and has a gentle slope toward the river, varying from 10 to 20 feet per mile, which makes the distribution of water for irrigation very easy.

The investigations discussed in the following report were confined to the section which derives its water supply from the Arkansas through the Lake Canal. This canal and the irrigated land under it are located on the north side of the river near the center of Otero County. In this district there are several other important canal systems. Other canals taking water from the north side of the river are the Colorado Land and Water Company's Canal, which heads about 16 miles east of Pueblo, and the La Junta and Lamar, or Fort Lyon Canal, heading about 3 miles west of La Junta. On the south side of the river are the Rocky Ford Canal; Land, Loan and Trust Company's Canal; the Fowler Colony Canal, heading near the town of Nepesta; the Otero Canal, heading about a mile north of the town of Fowler; and the Catlin and Rocky Ford canals, which head near Manzanola. These canals cover in the aggregate about 150,000 acres of land, and their systems comprise about 300 miles of main canal lines.

THE LAKE CANAL SYSTEM.

The main canal heads on the north bank of the river, about 2 miles east of Manzanola. (Map, Pl. XLVII.) From the head it takes a southeasterly course and follows the river for a distance of 11 miles; then, changing its course to northeast, the canal follows the general contour of the valley for 22 miles, where it encounters Horse Creek. Turning abruptly northwest, the line follows up the arroyo for a distance of 3 miles, where it crosses Horse Creek, and, making an abrupt turn, takes a southeasterly course for a distance of 3 miles and again

emerges upon the general slope of the valley. Beyond this point the canal has been outlined in a northeasterly direction for a distance of 12 or 15 miles. The construction of this part of the line has not been completed, the portion of the canal in actual use extending only to Horse Creek, into which is discharged the surplus water carried by the canal.

The construction of the Lake Canal was commenced September 25, 1889, and it was completed to Horse Creek, a distance of 25 miles, in April, 1892. The canal was carefully located, circular curves being used and great care being taken in the alignment. It was given, throughout its length to Horse Creek, a bottom width of 20 feet, an average depth in excavation of 3 feet, and side slopes of 1 to 1. The grade of the canal for the first mile is 5 feet per mile and throughout the remainder of the line 1.38 feet per mile. This gives the canal a capacity of 500 cubic feet per second. For this size of canal through soil of sandy loam this seems to be about the proper grade to give a mean velocity of from 3 to 3.5 feet per second, which is not high enough to cause erosion of the canal channel and is sufficient to prevent the deposition of silt. These are the limits which govern the velocity in a canal of this nature, which, having a late priority, receives water only during flood periods, when the volume diverted is large and the water carried is heavily charged with silt.

The first 3 miles of the line is along the bluffs which border the river. Here the construction work was quite heavy. The remainder of the canal traverses quite smooth country and no difficult construction was encountered. The earth excavated from the canal in this portion of the line was all placed on the lower side to form an embankment 6.5 feet above grade, leaving a berm of 6 feet.

With the exception of the head gates, waste ways, and larger lateral head gates there are no expensive structures on the system. The head gate (Pl. XLVIII, fig. 1) is placed on a slate rock foundation, and on either side is protected by heavy concrete wing walls. The width of the gate between wing walls is 56 feet, with a clear water opening of 45 feet, regulated by means of 10 gates, each 5 feet wide and 6 feet high, worked by levers. Above the head gate is a heavy crib structure, built for the purpose of protecting the head gates and to prevent drift from lodging against them. There are five waste ways by which the supply of the canal can be regulated, the surplus water being discharged into the river. These waste ways are built of timber, the gates being substantially of the same pattern as the head gates. The first of the waste ways is 1.75 miles from the head, and has four gates, each 4 feet wide by 8 feet high. The other four waste ways have each three gates 4 by 8 feet. The second waste way is 2.5 miles from the head, the third 3 miles, the fourth 9 miles, and the fifth 24.5 miles. Through this last waste gate the surplus water of the canal is dis-

FIG. 1.—HEAD GATE OF LAKE CANAL, SHOWING CRIB CONSTRUCTION.

FIG. 2.—HEAD GATE OF LAKE CANAL FROM BELOW.

DROP NO. 5, LAKE CANAL.

charged into Horse Creek. (Pl. XLIX.) The bottoms of the discharge openings of all the waste ways are placed 3 feet below the grade of the canal, which allows for the sluicing out of the greater part of the sediment deposited in the canal channel near the waste ways simply by raising the waste gates.

The water carried by the main canal is delivered to the irrigated land by small laterals placed at intervals along the canal and by four large distributing laterals. These latter, named in order as they are located on the canal, are the Jackson lateral, Reservoir No. 1 lateral, Ashley lateral, and Lewis lateral.

JACKSON LATERAL.

This lateral is taken from the main canal 12 miles from the head gate. It flows in a southeasterly direction for a distance of 6 miles and furnishes water to about 1,900 acres of land lying along the river.

RESERVOIR NO. 1 LATERAL.

This lateral derives its supply from Reservoir No. 1, which in turn is fed from the main canal. This reservoir occupies a natural basin located about 14 miles below the head of the canal at the upper end of a small valley or depression formed by a tract of high land situated between the main canal and the river. The reservoir has a surface area of 464.2 acres, and by means of a low embankment thrown across the southeast end of the basin water can be stored to the depth of 14 feet, giving a capacity of 4,247 acre-feet. The outlet of the reservoir is through a cut 3,000 feet long in the rim of the basin. The flow from the reservoir is controlled by a stone and concrete culvert provided with a vertical sliding gate at its upper end operated by a 3-inch screw. The reservoir is fed from the main canal through an inlet canal 0.75 mile in length. The elevation of the reservoir is about 18 feet below that of the main canal. This elevation is lost in the inlet canal by means of two vertical drops, one 6 feet in height, the other 12 feet. The Reservoir lateral is 8 feet wide on the bottom, with side slopes of 1 to 1, and the embankment on the lower side of the line is 4.5 feet above grade. From the outlet of the reservoir the lateral takes a northeasterly course and flows for a distance of 15 miles along the south side of the depression, the north side of which is traversed by the main line, and supplies water to 2,500 acres of land lying to the north. The reservoir is generally filled twice a year, once during the winter, which supply is drawn off for use during the early spring season; and again during the spring flood in May and June, this supply being held till later in the season, when the main canal is not drawing water from the river. During the flood season, when the canal is carrying a full supply of water, after the reservoir is filled, the Reservoir lateral is supplied direct from the main canal through an auxiliary

lateral which empties into the Reservoir lateral just below the outlet of the reservoir. This plan was adopted so that the irrigated lands under this lateral might have the muddy water direct from the river, which is valuable by reason of the immense quantity of silt that is carried onto the land. Another consideration of importance is that by carrying this muddy water direct to the land by means of the auxiliary lateral rather than through the reservoir, the deposit of mud and silt in the reservoir is prevented.

ASHLEY AND LEWIS LATERALS.

The Ashley and Lewis laterals are taken from the main line 22 miles below the head. The former flows in a southerly direction for 3 miles and irrigates 1,800 acres of land. The latter is 4 miles in length, flows southwesterly, and supplies 1,800 acres of land.

CANAL MANAGEMENT AND ORGANIZATION.

The canal system was originally an individual enterprise, built by H. R. Holbrook, of Pueblo, Colo. In July, 1892, the Laguna Canal Company was organized under the laws of Colorado with a capital stock of $200,000 to buy the canal system, which it did at that time, paying $150,000 of its capital stock therefor, since which time it has been operated by this company. The business affairs of the company are controlled by a board of three directors, two of the members of which are president and vice-president of the company, respectively. The management of the canal system is placed in the hands of a superintendent, whose duties are to see that the canal gives proper service, superintend all reconstruction work and repairs, and to in general look after the welfare of the canal system and irrigated lands under it. One man is employed at the head gate to regulate the supply admitted to the canal and superintend the distribution from the first 10 miles of canal. During the crop season there is one man who rides the remainder of the canal system and attends to the distribution from the main canal. This rider is usually employed for a period of six or eight months.

At the time the canal was constructed the State of Colorado owned about two-thirds of the land lying under the canal. The company bought 5,520 acres of this land, and leased, in 1892, 5,660 acres more for the purpose of reclamation. The company by agreement sells a perpetual water right for the leased lands for $10 per acre, while for other than State lands water rights are sold for $12.50 per acre, which according to terms of water contract entitle the purchaser to water at the rate of 1 cubic foot per second for 80 acres. These water rights are regarded as real estate and are evidenced by what is termed a water deed. No change in ownership of the canal system, either by volun-

tary deed or by process of law, can affect a water right, as it is thoroughly vested in the purchaser.

Since the canal has rather a late priority, it is entitled to water from the river only during the spring flood season and at other times when the river's flow is increased beyond the demands of prior appropriators. Owing to this fact the flow in the canal is intermittent, and it has been found that a flow of 1 cubic foot of water per second during the times when the canal is carrying water is not sufficient to irrigate 80 acres of land, and the company therefore gives to each water-right holder gratuitously a deed for 50 per cent more water than he has bought, making in all 1.5 cubic feet per second for each 80 acres of land. Head gates of all laterals are built to carry from two to three times the amount of water sold, so that farmers can draw a large head when there is an abundance of water and get over their ground quickly. When there is a small amount of water, rotation of the water among the irrigators is resorted to.

WATER CONTRACT AND DEED.

The water contract entered into by the canal company and water consumer provides that the canal company shall deliver to the consumer a continuous flow of water of 1 cubic foot per second for each 80 acres of land to be irrigated; that the payment of consideration named may be made on the installment plan, the interest on deferred payments being payable semiannually with interest at the rate of 1 per cent per month after maturity; that when the amount of such consideration shall have been paid in full a water deed, conveying to consumer the water right mentioned in contract, shall be executed; and that this transfer of water right shall be made subject to the following conditions, to which the consumer expressly agrees:

(1) Water shall be used solely for irrigation and domestic purposes, and only upon the lands mentioned specifically in the contract.

(2) That no assignment of water contract or deed, or relocation for use of water upon other lands than those described in contract, shall be made without consent of the canal company.

(3) The canal company reserves the right to distribute water from the canal in accordance with such rights and priorities as may subsequently be established or decreed by law.

(4) When consumer has sufficiently irrigated his crops he shall shut the water off at the lateral head gate and not allow it to run to waste.

(5) Lateral head gates and measuring weirs or flumes are placed in position by the company at expense of consumer, who is required to make necessary repairs and keep such structures in order.

(6) The company shall maintain the canal in good condition and shall sell no more water rights than the capacity of the canal will

warrant. To meet expenses of maintaining, repairing, and operating the canal system the company has the right of levying an annual assessment of $25 upon each water right. On the failure of any consumer to pay such tax within ten days after being notified by the company of the assessment, the company may shut off consumers' water until his assessment is paid in full, together with interest on the same at the rate of 1 per cent per month from date of assessment until paid. In event of default of payment the company, at its option, may declare either contract or deed forfeited and void.

(7) If, in case of accident to the canal system, or owing to drought, or by reason of the use of other canals having prior rights the supply in the canal is diminished below its estimated capacity, the company shall distribute such water as may flow pro rata to the water-right holders in the canal.

(8) The consumer grants to the canal company the necessary right of way upon which to construct laterals for supplying lands lying below, provided said laterals are built where they will do the least harm to consumer's land. The canal company shall have right of roadway along the banks of its main canal and main laterals, and when fences are built by consumer, which would obstruct such roadway, suitable gates for passage of wagons shall be constructed and maintained by consumer.

The assessment provided for in the contracts amounts practically to 31 cents per acre. This, it has been found, is hardly enough to meet the annual expenses of the system, which approximate $6,000, owing to a considerable number of water rights in the canal remaining unsold. When the amount of land irrigated under the system reaches 20,000 acres it is estimated that the annual assessment of $25 per water right will be sufficient to defray all operating expenses of the system.

During the years 1900 and 1901 the timber in the head gate was renewed at a cost of $3,000, and extensive improvements made at the first three waste gates at a cost of $2,500. Two new lateral head gates were also constructed at a cost of $400 each, one for Jackson lateral, the other for Reservoir No. 1 lateral. When the canal was first constructed the smaller laterals were provided with simple wooden head gates. These failed to prove satisfactory, and during the last two years, as fast as they have become in bad condition, have been replaced by a new device, consisting of sewer pipe 8 to 18 inches in diameter, according to size of lateral, which pierces the canal bank, and is provided at its upper end with a cast frame and steel sliding gate for regulating the flow in the lateral.

Each spring and fall all bars and obstructions formed by weeds and brush are cleaned out. In this way the canal is kept in splendid condition, and is always ready to receive water at flood intervals and during the irrigation season.

SEEPAGE INVESTIGATION.

On June 9 measurements were made on the upper 18 miles of the Lake Canal for the purpose of determining the amount of water lost from this portion of the system. The conditions which obtained at the time the measurements were made were very favorable to the accurate determination of the loss. For a considerable length of time the canal had been carrying a full supply of water, and the greater part of the land under the system had been thoroughly watered; as a result little water was being drawn from the canal. In the whole length of 18 miles only 6 laterals were drawing water. The upper measurement was made at the rating flume located 2 miles below the head gate. The lower measurement was made at Shelton's Bridge, 18 miles below the head gate and 16 miles below the rating flume. The results of the test are given in the following summary:

Summary of measurements in Lake Canal, June 9, 1901.

[In cubic feet per second.]

Discharge at rating flume		456.33
Diversions:		
Overflow No. 1	1.68	
Overflow No. 2	.10	
Lateral No. 1	4.60	
Lateral No. 2	.05	
Lateral No. 7	2.64	
Lateral No. 8	5.65	
Jackson lateral	51.62	
Lateral No. 12	3.02	
Reservoir No. 1 lateral	180.00	
Discharge at Shelton's Bridge	171.37	
		420.73
Total loss		35.60
Loss per mile		2.23
Percentage of loss		7.80

In the above computations no allowance has been made for loss by evaporation from the canal surface. On the day the measurements were made the evaporation[a] (twenty-four hours) was 0.4 inch or 0.033 foot. Assuming that the water surface of the canal throughout the 16 miles covered was 25 feet in width, the loss from evaporation would amount to 0.8 cubic foot per second for the twenty-four hours. This, it will be noticed, is very small when compared with the total loss and can be ignored, and the whole loss as shown by the measurement may be charged to seepage.

In many localities crops are considerably damaged by white alkali unless care is taken to prevent it. Its presence is undoubtedly due to

[a] The evaporation was measured at the head gate of canal. See under discussion of duty of water, in succeeding pages.

the extravagant use of water under the canal during periods of plentiful water supply, when all the water that the ground will possibly hold is run on. The question whether the effects of the alkali brought to the surface, due to the saturated condition of the ground, are more than counterbalanced by the results obtained from an increased application of water, or vice versa, is one which individual localities must solve for themselves. Under a canal where the water supply is none too plentiful it seems that the presence of alkali could be coped with in many ways so as to decrease its damaging effects and yet not decrease the amount of water applied.

On a number of places tile drains have been put in and have solved the problem of washing out the alkali. On other farms open drains have produced good results. Where by reason of the slope of the land drainage is impracticable, other methods of reducing the evil effects of alkali have been used with good effect. Rapidly flooding the land affected washes off a considerable portion of the salts that collect on the surface; plowing under coarse manure, old straw, beet tops, or alfalfa, together with thorough cultivation, has also been productive of good results.

DUTY OF WATER.

RAINFALL AND EVAPORATION.

During the period from April 13 to December 1 record of the rainfall and evaporation was kept. The instruments were placed near the head of the canal, the record being kept by Mr. J. E. Lewis, care taker of the head gate, who also attended to the register installed on the rating flume 2 miles below the head gate. The record obtained is given in the following table:

Rainfall and evaporation, Arkansas Valley, Colorado, 1901.

Week ending—	Rainfall.	Evaporation.	Week ending—	Rainfall.	Evaporation.
	Inches.	*Inches.*		*Inches.*	*Inches.*
April 20	0.10	1.40	August 24	0.02	1.94
April 27	.00	1.75	August 31	1.05	3.20
May 4	.07	2.64	September 7	.11	1.62
May 11	.02	1.87	September 14	.00	1.60
May 18	.35	1.52	September 21	.00	1.85
May 25	.29	2.46	September 28	.00	2.00
June 1	.40	1.72	October 5	.00	1.45
June 8	.00	1.60	October 12	.40	1.25
June 15	.10	2.95	October 19	.00	.90
June 22	.00	2.05	October 26	.00	.80
June 29	.00	3.10	November 2	.00	1.00
July 6	1.10	3.85	November 9	.00	.75
July 13	.00	2.60	November 16	.00	.65
July 20	.34	2.98	November 23	.00	.45
July 27	.07	2.29	November 30	.00	.45
August 3	.00	2.50			
August 10	.22	2.35	Total	5.05	61.66
August 17	.11	2.12			

MEASURING FLUME, LAKE CANAL.

DUTY OF WATER UNDER ENTIRE SYSTEM.

In order to determine the amount of water applied to the irrigated land under the Lake Canal during the season of 1901 a careful record was kept of the amount of water flowing in the canal. This record was secured by means of a water register placed on the measuring flume (Pl. L) 2 miles below the head of the canal. From this record the following table was derived, which shows the amount of water received by the entire irrigated area under the canal, subject to the losses shown in the preceding pages:

Discharge of Lake Canal, season 1901.

Day.	May.	June.	July.	August.	September.
	Acre-feet.	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*
1	....	590.30	198.14	0.00	686.74
2	....	486.33	238.73	0.00	661.68
3	....	630.85	466.84	0.00	250.49
4	....	513.54	413.71	0.00	0.00
5	....	590.18	121.31	0.00	0.00
6	....	715.47	0.00	650.23	0.00
7	....	830.17	0.00	446.64	0.00
8	....	875.17	0.00	0.00	0.00
9	....	796.25	0.00	0.00	0.00
10	0.00	712.83	0.00	0.00	0.00
11	0.00	402.42	0.00	0.00	0.00
12	0.00	348.22	0.00	376.67	0.00
13	0.00	340.45	0.00	655.56	0.00
14	0.00	302.91	0.00	438.60	0.00
15	0.00	381.74	0.00	0.00	0.00
16	74.73	439.07	0.00	0.00	0.00
17	389.30	478.71	0.00	0.00	0.00
18	343.32	433.88	0.00	0.00	0.00
19	357.67	408.55	0.00	0.00	0.00
20	488.42	411.44	0.00	403.25	0.00
21	686.65	435.60	0.00	192.27	0.00
22	735.70	437.35	0.00	0.00	0.00
23	738.96	459.16	0.00	0.00	0.00
24	726.85	519.37	0.00	0.00	0.00
25	726.05	510.23	0.00	0.00	0.00
26	712.64	745.37	74.30	0.00	0.00
27	824.27	794.93	338.60	0.00	0.00
28	781.72	784.28	475.78	0.00	0.00
29	736.08	483.09	420.63	0.00	0.00
30	626.09	18.86	127.46	0.00	0.00
31	750.46	....	0.00	219.84	....
Total	9,698.91	15,876.72	2,875.50	3,383.05	1,598.91

During the season there was 14,500 acres irrigated under the canal. Most of this land is in the depression between the main line and the Reservoir lateral. As Reservoir No. 1 had been filled before the register record on the main canal was started, and as this water was used under the Reservoir lateral, correction is made in the following summary for this additional amount of water applied. The amount is estimated on the capacity of the reservoir:

Duty of water under Lake Canal.

Area irrigated ....acres..	14,500.000
Water used through canal ....acre-feet..	33,433.090
Water used from Reservoir No. 1 ....do....	4,000.000
Depth of water used in irrigation ....feet..	2.582
Depth of rainfall ....foot..	.420
Total depth of water received by land ....feet..	3.002

At the beginning of the season it was also planned to make a study of the use of water under Jackson lateral, and accordingly a rating flume and water register were installed upon it near the main canal. The location chosen, however, was not a satisfactory one, for silt was deposited in the canal channel and rating flume in such quantities as to render the record of flow obtained worthless.

DUTY OF WATER UNDER LEWIS LATERAL.

Before the irrigation season opened a rating flume was also constructed on the Lewis lateral. The record of flow in this lateral was obtained from daily gauge readings made by the ditch rider on the lower section of the canal. This record, although it is not so accurate as it would have been had it been taken by means of a water register, will serve to show the use of water under this lateral, and the results obtained will be sufficiently accurate for comparison with those obtained for the entire system. The table following shows the flow of Lewis lateral from May 20 to September 30, inclusive:

Discharge of Lewis lateral, season 1901.

Day.	May.	June.	July.	August.	September.
	Acre-feet.	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*
1		117.80	67.82	0.00	102.34
2		133.29	75.56	0.00	135.25
3		149.54	125.94	0.00	102.34
4		80.32	102.34	0.00	0.00
5		80.32	0.00	0.00	0.00
6		80.32	0.00	44.23	0.00
7		80.32	0.00	67.82	0.00
8		91.22	0.00	0.00	0.00
9		99.16	0.00	0.00	0.00
10		107.10	0.00	0.00	0.00
11		32.13	0.00	0.00	0.00
12		42.20	0.00	130.50	0.00
13		42.20	0.00	125.94	0.00
14		52.26	0.00	125.94	0.00
15		63.90	0.00	0.00	0.00
16		63.90	0.00	0.00	0.00
17		75.56	0.00	0.00	0.00
18		57.91	0.00	0.00	0.00
19		40.26	0.00	0.00	0.00
20	67.82	40.26	0.00	0,00	0.00
21	93.60	40.26	0.00	130.50	0.00
22	102.34	40.26	0.00	75.56	0.00
23	102.34	91.22	0.00	0.00	0.00
24	93.60	91.22	0.00	0.00	0.00
25	93.60	91.22	0.00	0.00	0.00
26	102.34	125.94	0.00	0.00	0.00
27	114.03	125.94	67.82	0.00	0.00
28	117.80	130.50	67.82	0.00	0.00
29	102.34	91.22	40.26	0.00	0.00
30	117.80	0.00	40.26	0.00	0.00
31	133.29		0.00	0.00	
Total	1,240.90	2,357.75	587.82	700.49	339.93

The total area under this lateral is given as 1,800 acres, and it is estimated that about 1,680 acres of land were irrigated during the season. The crops grown on this area are not different from those under

other sections of the system. In the following table is given the duty of water under this lateral:

Duty of water under Lewis lateral.

Area irrigated	acres..	1,680.000
Water used	acre-feet..	5,226.890
Depth of water used in irrigation	feet..	3.111
Depth of rainfall	foot..	.420
Total depth of water received by land	feet..	3.531

CROPS.

There is probably no crop grown in the temperate zone which can not be raised in some section of the Arkansas Valley. Even tobacco and cotton have been successfully grown at the United States experiment station situated at Rocky Ford. With an average altitude of 4,200 feet above sea level, a long growing season free from extreme climatic changes, an extremely rich soil of sandy loam, and, in most localities, a plentiful water supply for irrigation purposes, the agricultural possibilities of the valley would be hard to excel.

The crops most generally grown in the valley are fruit, including apples, pears, peaches, apricots, grapes, and small fruits; alfalfa, produced both for hay and seed; sugar beets, corn, small grain, watermelons, cantaloupes, and vegetables.

Under the Lake Canal, owing to the nature of the water supply, the principal crops raised are alfalfa, grain, and Mexican beans. Other crops, such as sugar beets, melons, cantaloupes, tomatoes, and potatoes, are also raised, but with varying success, for the reason that water is not always available when these crops demand it, and they suffer if not irrigated. There are quite a number of orchards under the canal, but as yet these are young and have not commenced bearing. The average yield of alfalfa for three cuttings is from 5 to 7 tons per acre. At the current price of $5 to $7 per ton this represents a return of $25 to $50 per acre. During 1901 the water supply was exceptionally short, and the alfalfa yield for the year was reduced to 2 to 5 tons per acre, two crops only, in the majority of cases, being cut, one for hay, the other for seed. The average yield of seed was 2 to 5 bushels per acre, which, at the current price of $4, gave a return from the seed alone of from $8 to $20 per acre. The yield of sugar beets ranged from 7 to 20 tons per acre, which crop brought $4 to $5 per ton. Mexican beans averaged 10 to 14 bushels per acre, and gave a return of $15 to $20 per acre. The report of other crops grown under the canal during the season showed that owing to the very dry season their yield was reduced very much below the normal.

Had the water applied to the irrigated area been available at times when the crops most needed water, the amounts applied, as shown in the above summaries, would have been ample to produce abundant crops. But as it was, the greater part of the water was applied during the period from May 10 to June 29, and during the remainder of the year the shortage seriously affected the growth of crops. The following table shows the average depth of water received by the land under the canal each month during the season:

Monthly depth of water received by irrigated land, May–September, 1901.

Month.	Depth applied by canal.	Depth of rainfall.
	Feet.	*Foot.*
May	0.669	0.060
June	1.095	.042
July	.198	.126
August	.233	.117
September	.110	.010
Total	2.305	.355

Another factor which to a great extent affects the use of water in this section is the practice of irrigating during the winter months. During the winter season, whenever practicable, water is supplied by the canal, and considerable irrigation of winter wheat and alfalfa is accomplished. Water is also run on land to be put into crops. This has the effect of facilitating cultivation and of saturating the ground to a considerable depth, thus making it possible to raise crops on such land with a very much less supply of water during the irrigation season than would otherwise be required. Whether the harmful effects of alkali caused by this practice of saturation are more than counterbalanced by the beneficial results obtained is a matter which must be left to future investigations.

ACKNOWLEDGMENTS.

Acknowledgment is here made of the generous assistance rendered and of the numerous courtesies extended by the officers of the Laguna Canal Company, by means of which the investigation in Arkansas Valley was made possible.

NEBRASKA.

IRRIGATION UNDER THE GREAT EASTERN CANAL, PLATTE COUNTY, NEBR., IN 1901.

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INTRODUCTION.

The investigations under this canal were more extensive in 1901 than in 1900 only in the sense that the season of record at the register station on the main canal was longer. The register was in service at the Looking Glass Flume, east of Genoa, Nebr., from May 19 to September 7, inclusive, a period of one hundred and twelve days, as against a period of only thirty-five days in 1900. The registering instrument was an old one, and occasionally for a short interval of time would fail to furnish a record. These interruptions of the record amount in all to a little less than one-seventh of the entire time that the register was in service. To supply these omissions the expedient has been adopted of taking the mean of the average rates of discharge through the flume for a day just preceding and one just after the failure of the register.

On this basis it has been estimated that 5,879 acre-feet passed through the flume from May 19 to September 7. This water was applied to 2,509 acres. If all the water reached the fields it would be sufficient to cover them to a depth of 2.343 feet, or 28.12 inches.

The best ground for a discussion of the results of the work of 1901 is found in a comparison with those obtained in 1900. The following points have been noted:

In 1900 the period of record extended only from July 14 to August 17, and the depth of water applied during that time was 14.22 inches. For this same period in 1901 the depth is 15.04 inches.

In 1900 it was noted that extended correspondence with the irrigators who had used the measured water indicated that water was not applied to more than 10 per cent of the land at times outside of the limits of July 1 to August 20. In 1901 44 per cent of the total recorded flow was registered outside of those dates.

The following tabulation of rainfall is designed to set forth facts which may reasonably be supposed to affect the extent to which water would be used for irrigation in the different years:

Total rainfall during growing season, dating from April 1.

	To Apr. 30.	To May 31.	To June 30.	To July 31.	To Aug. 31.	To Sept. 30.
	Inches.	*Inches.*	*Inches.*	*Inches.*	*Inches.*	*Inches.*
Normal [a]	3.10	7.14	11.40	15.05	18.14	21.10
1900	5.10	7.60	10.02	14.16	21.13	30.66
1901	2.15	3.69	7.90	8.70	9.38	16.24

[a] The normal is based on records kept at George Truman's farm, about 4 miles west of Monroe, which do not include the rainfall for 1901. The others are the average of records at Truman's farm, at Monroe and at Columbus.

In April, May, and June of 1900 the total rainfall amounted to about 88 per cent of the normal for the three months. In 1901, for the same three months, the total rainfall was only 69 per cent of the normal. The excess, amounting to 1.79 inches in June, 1901, over the rainfall for the same month in 1900, is not sufficient to offset the deficiency in April and May of 1901.

In 1900 the rainfall in July was 113 per cent, and in August 225 per cent of the normal. The corresponding figures for 1901 are 22 per cent of the normal for each month.

The records and information concerning the water used in irrigation, taken in connection with the foregoing observations concerning rainfall, indicate that the irrigators in 1900 took advantage of the fact that the rainfall during the early part of that season was sufficient to permit the postponement of irrigation operations, while in 1901, on account of the deficiency of rainfall in April and May, the use of water was commenced early. However, it seems that after the application of water was begun, it proceeded at about the same rate in the two seasons, notwithstanding the fact that the late season of 1901 was markedly deficient in rainfall and that the reverse was true in 1900.

IRRIGATION AS CROP INSURANCE.

The late season of 1901, under this canal, furnished a good example of the part which irrigation may play as an insurance of crops in regions where the rainfall is ordinarily sufficient to mature at least a fair crop. The drought in July and August of this year ruined the corn crop in the vicinity of the canal, except where it was saved by irrigation. The irrigated fields returned full yields.

OBSERVATIONS ON THE FARM OF THE WESTERN SEED AND IRRIGATION COMPANY.

The measurement of water used in irrigation on the farm of the Western Seed and Irrigation Company, near Monroe, in 1901, was made at the same point as in 1900. More land was irrigated by the

measured water than in the previous year, but the records of the irrigations and of yields which were furnished is not as much in detail nor as suitable for complete analysis. The water in 1900 was handled by a man who had thorough experience as an irrigator, while in 1901 the work constituted a young man's first experience in that line. The following table gives the results of the measurements made and the crop return for the season (fig. 8):

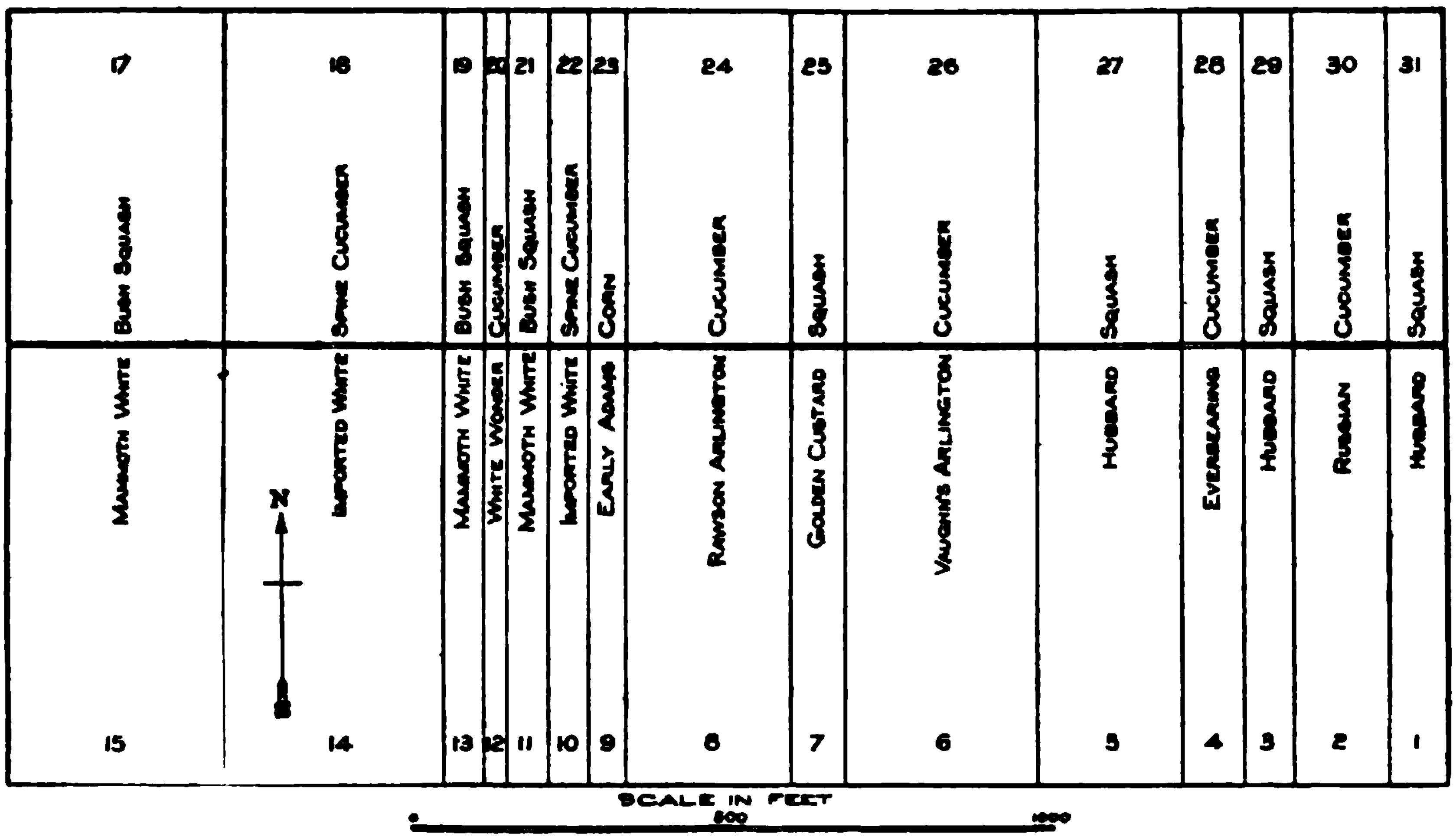

FIG. 8.—Irrigated tracts on farm of Western Seed and Irrigation Company, near Monroe, Nebr., 1901.

Results of irrigation on farm of Western Seed and Irrigation Company, Monroe, Nebr., 1901.

Product.	Lot.	Times.	Duration.	Date.	Area.	Water used.	Average depth.	Average head.	Rainfall.[a]	Total depth received.
			Hrs.	*1901.*	*Acres.*	*Acre-feet.*	*Feet.*	*Cu. ft. per sec.*	*Foot.*	*Feet.*
Mammoth White bush squash	13	1st	8	July 21	0.98	0.3306	0.337	0.50	0.492	1.524
		2d	4	Aug. 29	.98	.6813	.695	2.06		
	19	1st	3	July 22	.73	.3198	.438	1.29	.492	.930
	15	1st	5	July 21	5.27	.1025	.019	.25	.492	.511
	17	1st	6	July 22	4.04	.6401	.158	1.29	.492	.650
	11	1st	10	July 20	1.01	(b)			.492	3.675
		2d	8	Aug. 10	1.01	1.5716	1.560	2.38		
		3d	4	Aug. 29	1.01	1.6394	1.623	4.96		
	21	1st	3	July 23	.75	.4759	.635	1.92	.492	1.127
Imported White Spine cucumber	10	1st	10	July 20	1.01	(b)			.492	1.511
		2d	2	Aug. 9	1.01	.5146	.510	3.11		
		3d	2	Aug. 29	1.01	.5140	.509	3.11		
	14	1st	6	July 21	5.26	.2562	.049	.52	.492	1.532
		2d	14	Aug. 28	5.26	2.5075	.477	2.17		
		3d	8	Aug. 30	5.26	2.7040	.514	4.09		
	22	1st	2	July 23	.75	.3173	.423	1.92	.492	1.363
		2d	3	Aug. 23	.75	.3363	.448	1.35		
	18	1st	3	July 23	3.99	.3198	.080	1.29	.492	.572
White Wonder cucumber	12	1st	10	July 20	.49	(b)			.492	1.919
		2d	2	Aug. 30	.49	.6992	1.427	4.23		
	20	1st	3	July 23	.37	.4759	1.286	1.92	.492	1.778
Early Adams corn	9	1st	10	July 19 and 20	.94	(b)			.492	1.748
		2d	3	Aug. 9	.94	1.0488	1.116	4.23		
		3d	3	Aug. 21	.94	.1314	.140	.53		
	23	1st	3	Aug. 3	.70	(b)			.492	.492

[a] Rainfall is the mean of precipitation, June 1 to August 31, at Monroe and at a station on George Truman's farm, about 4 miles west of Monroe.
[b] No record.

Results of irrigation on farm of Western Seed and Irrigation Company, Monroe, Nebr., 1901—Continued.

Product.	Lot.	Times.	Duration.	Date.	Area.	Water used.	Average depth.	Average head.	Rainfall.[a]	Total depth received.
			Hrs.	*1901.*	*Acres.*	*Acre-feet.*	*Feet.*	*Cu. ft. per sec.*	*Foot.*	*Feet.*
Rawson Arlington cucumber	8	1st	3	July 19	3.98	(b)				
		2d	12	Aug. 9	3.98	1.7319	0.435	1.74	0.492	1.436
		3d	10	Aug. 29	3.98	2.0250	.509	2.45		
	24	1st	3	Aug. 3	2.94	(b)			.492	.832
		2d	5	Aug. 23	2.94	.9983	.340	2.42		
Golden Custard squash	7	1st	6	July 17	1.29	(b)			.492	.863
		2d	2	Aug. 8	1.29	.4788	.371	2.90		
	25	1st	5	Aug. 6	.94	.9521	1.013	2.30	.492	1.505
Vaughn Arlington cucumber	6	1st	10	July 18 and 19	4.65	(b)			.492	.492
	26	1st	6	Aug. 6	3.42	.9257	.271	1.87	.492	.963
		2d	5	Aug. 24	3.42	.6843	.200	1.66		
Hubbard squash	5	1st	5	July 18	3.49	(b)			.492	.381
		2d	10	Aug. 21	3.49	1.3581	.389	1.64		
	c27				2.52				.492	.492
	3	1st	4	July 18	1.22	(b)			.492	1.011
		2d	4	Aug. 22	1.22	.6336	.519	1.92		
	c29				.88				.492	.492
	1	1st	2	July 17	1.49	(b)			.492	.928
		2d	4	Aug. 21	1.49	.6377	.428	1.93		
	c31				.82				.492	.492
Ever-bearing cucumber	4	1st	3	July 18	1.50	(b)			.492	.492
	c28				1.08				.492	.492
Russian cucumber	2	1st	4	July 18	2.26	(b)			.492	.720
		2d	3	Aug. 31	2.26	.5156	.228	2.08		
	c30				1.62				.492	.492

a Rainfall is the mean of precipitation, June 1 to August 31, at Monroe and at a station on George Truman's farm, about 4 miles west of Monroe.
b No record.
c Not irrigated. Part of a reclaimed swamp.

Yield of crops on farm of Western Seed and Irrigation Company, Monroe, Nebr., 1901.

Product.	Lots.	Yield of seed per acre.
		Pounds.
Mammoth White bush squash	13, 19, 15, 17, 11, 21	432
Imported White Spine cucumber	10, 14, 22, 18	282
White Wonder cucumber	12, 20	122
Early Adams corn	9, 23	a 36.5
Rawson Arlington cucumber	8, 24	128
Golden Custard squash	7, 25	486
Vaughn Arlington cucumber	6, 26	245
Hubbard squash	5, 27 b, 3, 29 b, 1, 31 b	c 150
Ever-bearing cucumber	4, 28 b	236
Russian cucumber	2, 30 b	252

a Bushels.
b Not irrigated, part of a reclaimed swamp.
c Yield per acre is exclusive of lots 3, 29, 1, and 31, the entire crop on these lots being destroyed by bugs.

In 1900 the yield of seed crops was partially destroyed by floods resulting from rains in the early fall, while in 1901 the only damage to crops was that which the squash suffered from bugs.

Comparing the yields of the two years, it is noted that two varieties of squash in 1901 yielded at a rate about 70 per cent in excess of the average in 1900, while one variety, which had been the especial prey of the bugs, yielded at only about one-half of the rate in 1900.

The average rate of yield of cucumbers in 1901 exceeded the rate in 1900 by one-third.

The land irrigated by measured water in 1900 constitutes the south-

ern portion of the tract irrigated in 1901. The northern portion is new land, and it is to be regretted that separate records were not kept of the yields as well as of the irrigations on the two portions.

The general conditions and results in the two years of record may be summarized and compared thus: In 1900, old land, experienced irrigator, fairly even distribution of water, crops flooded by heavy rains before harvesting; in 1901, partly new land, inexperienced irrigator, no damage from rains, some damage from insects. Yields in 1901 are from 30 to 70 per cent in excess of those obtained in 1900.

In view of the fact that the only unfavorable condition encountered in 1900 was the flood in the fall of the year, and that in the face of more unfavorable conditions in the succeeding year the yields of that year exceeded materially those of 1900, it seems fair to conclude that the estimate of the manager of the farm to the effect that at least half of the crop of 1900 was destroyed by the flood, was not exaggerated.

SEEPAGE MEASUREMENTS ON THE CULBERTSON CANAL.

The water supply for the Culbertson Canal is diverted from Frenchman River at Palisade, Nebr., and is carried through some 30 miles of canal. The canal was constructed under a misapprehension as to the magnitude of the available water supply, and hence has never carried more than a fraction, perhaps not exceeding one-third, of the amount of water for which it was designed.

On August 7 and 8, 1894, at the instance of Mr. C. P. Hubbard, who was at that time manager of the enterprise, the writer undertook a series of measurements to determine the extent of the loss of water from the canal by seepage and evaporation combined.

It was considered essential to the reliability of results that no water should be drawn from the canal during the progress of the measurements. It is not known that there was any instance of disregard of this precaution.

Following is a table of the results of the measurements of discharge of the canal:

Measurements of discharge.

Number of measurement.[a]	Place.	Time.	Discharge.	Loss in distance from last place of measurement.	Distance from last place of measurement.	Loss per mile in distance from last place of measurement.
			Cu. ft. per sec.	*Cu. ft. per sec.*	*Miles.*	*Cu. ft. per sec.*
2	Flume No. 1	2-3 p. m., Aug. 7	80.62			
3	Flume No. 2	4 p. m., Aug. 7	73.86	6.76	3.485	1.94
4	Flume No. 3	6 p. m., Aug. 7	68.90	4.96	2.462	2.01
5	Flume No. 4	7 p. m., Aug. 7	68.80	.10	1.098	.09
6	Flume No. 5	8 p. m., Aug. 7	67.52	1.28	2.746	.47
7	Flume No. 6	10 a. m., Aug. 8	61.22			
8	Flume No. 7	11.30 a. m., Aug. 8	55.82	5.40	2.159	2.50
9	Flume No. 8	1.30 p. m., Aug. 8	55.17	.65	2.803	.23
10	Flume No. 9	3.30 p. m., Aug. 8	51.13	4.04	1.780	2.27
11	Flume No. 10	5-5.30 p. m., Aug. 8	25.19	25.94	8.730	2.97

[a] No. 1 does not belong to the series.

The great variation in the rate of loss of water per mile from the canal, as noted in the last column of the table, may be due to any one or a combination of the following circumstances:

The rate at which the water enters the canal at the head gate, being unavoidably somewhat variable, waves of increase or decrease of flow may pass down the canal. If a wave of increase were overtaken by the measuring party between two measurements the difference between the results of those gaugings would be more than the normal. On the other hand, if a wave of decrease were similarly overtaken the difference would be less than the normal.

Differences in the nature or condition of the soil forming the bed and sides of the channel affect the rate of loss.

The unavoidable inaccuracies of measurement by meter will affect the values of quantities in the last column in considerably greater proportion than those in the fourth column of the table.

Summary of seepage measurements, Culbertson Canal.

No.	Place.	Discharge.	Loss.	Distance.	Loss per mile.	
		Cu. ft. per sec.	*Cu. ft. per sec.*	*Miles.*	*Cu. ft. per sec.*	*Per cent.*
2	Flume No. 1	80.62				
6[a]	Flume No. 6	67.52	13.10	9.791	1.34	1.66
7[b]	Flume No. 6	61.22				
10	Flume No. 9	51.13	10.09	6.742	1.50	2.45
11	Flume No. 10	25.19	25.94	8.730	2.97	5.81

[a] Taken at 8 p. m., August 7, 1894. [b] Taken at 10 a. m., August 8, 1894.

From the head to flume No. 9 the canal was some three or four years old. Water had been running but a few weeks in the length of the canal from flume No. 9 to flume No. 10. The largely increased seepage from the new portion of the ditch is strikingly shown by the figures of the table.

For a large part of the distance above flume No. 9 the canal is located on sidehill. Below that point it lies to a considerable extent on a tableland. The soil is of a loose character, although containing no sand except near the river, and washes easily.

MISSOURI.

IRRIGATION EXPERIMENTS AT THE MISSOURI EXPERIMENT STATION.

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INTRODUCTION.

Experiments in irrigating apples, strawberries, and nursery stock were conducted in the summer of 1901 by the Missouri Experiment Station in cooperation with the Office of Experiment Stations of the United States Department of Agriculture, by Mr. W. L. Howard, assistant horticulturist at the Missouri station. On account of the limited supply of city water in the early part of the season, the irrigating was not begun on any of the crops named above, except strawberries, until August 23.

SOIL.

The soil upon which these experiments were made is a fertile, heavy limestone clay, about 12 inches deep, underlaid with a stiff, retentive clay subsoil. This land is inclined to bake after a rain, and is very retentive of moisture, but does not yield it readily to the growing crops. All plats had good surface drainage.

SEASON.

The season during which the experiments were made was about normal during January, February, and March. With the exception of the last six days of the month, the weather during April was unusually cool, the temperature averaging about 7° below the normal, but the last week was very warm. From April 1 to April 17 the precipitation was about normal, but only a trace fell during the remainder of the month.

The month of May averaged slightly cooler than usual. The total precipitation was 0.35 inch, which is only 6 per cent of the normal, and is the least amount ever recorded at this station for May. The soil became very dry and nearly all growing crops suffered severely.

June averaged about 4° warmer than usual, the last ten days of the month being exceptionally warm. The rainfall was remarkably light, the total for the month being only 1.23 inches, or about 27 per cent of the normal. Corn, oats, and all other crops except wheat made little or no progress.

July was the warmest month of which there is any record in this State, the mean temperature being 85.2°—10° above normal. There

were twenty-six days with maximum temperature above 90°, and eighteen days on which the temperature reached 100° or above, the highest being 111° on the 12th. The precipitation of the month, 2.74 inches, was about 56 per cent of the normal. Rain fell on twelve days, but on only two did the fall exceed one-half inch. The drought was greatly intensified by the extreme heat, and vegetation dried up rapidly.

The month of August was also warmer than usual, the excess in temperature averaging about 3° per day. Good showers fell on the 3d and 4th, but during the remainder of the month the rainfall was extremely light, the total for the month being only 1.67 inches, a deficiency of 1.14 inches. Vegetation improved somewhat after the rain of the 4th, but during the latter part of the month it again became parched and dry.

The mean temperature of September was practically normal, but the long drought continued, the precipitation of the month being only 1.37 inches—2.23 inches less than normal.

October was somewhat warmer than usual, the excess in temperature averaging 2.6° per day. The total precipitation was 1.16 inches, which is only 0.24 inch less than the normal.

The total precipitation from April 7 to October 31 was 10.8 inches, which is a deficiency of 16.57 inches, or only 39 per cent of the normal.

The following tables show the departure from normal, by weeks, during the growing season:

Departure from normal temperature and precipitation at Columbia, Mo., during season of 1901.

Week ending—	Temperature.				Precipitation.		
	Mean.	Departure from normal.	Accumulated departure.	Maximum for week.	Total.	Departure from normal.	Accumulated departure.
1901.	°F.	°F.	°F.	°F.	*Inches.*	*Inches.*	*Inches.*
April 7	44.0	− 6.3	− 6.3	68	0.91	+0.02	+ 0.02
April 14	52.3	− 2.7	− 9.0	65	.98	− .04	− .02
April 21	47.3	−12.0	−21.0	67	.49	− .61	− .63
April 28	63.6	+ 3.6	−17.4	86	Trace.	−1.17	− 1.80
May 5	72.0	+11.7	− 5.7	89	Trace.	−1.24	− 3.04
May 12	58.1	− 4.1	− 9.8	81	.11	−1.24	− 4.28
May 19	66.1	+ 1.6	− 8.2	89	.19	−1.21	− 5.49
May 26	61.3	− 5.4	−13.6	88	.05	−1.27	− 6.76
June 2	63.7	− 5.1	−18.7	88	.00	−1.24	− 8.00
June 9	69.9	− 3.7	−22.4	96	.68	− .46	− 8.46
June 16	78.7	+ 3.7	−18.7	94	.31	− .74	− 9.20
June 23	80.0	+ 5.0	−13.7	100	.22	− .76	− 9.96
June 30	87.9	+12.9	− .8	104	.02	−1.03	−10.99
July 7	85.3	+10.0	+ 9.2	106	.27	− .85	−11.84
July 14	85.0	+ 9.0	+18.2	111	Trace.	−1.18	−13.02
July 21	85.6	+ 8.6	+26.8	107	1.43	+ .30	−12.72
July 28	87.7	+10.7	+37.5	110	.19	− .84	−13.56
August 4	78.7	+ 1.7	+39.2	100	2.07	+1.22	−12.34
August 11	77.7	+ .7	+39.9	97	.34	− .84	−12.68
August 18	78.3	+ 1.3	+41.2	94	.11	− .44	−13.12
August 25	79.3	+ 3.3	+44.5	102	Trace.	− .55	−13.67
September 1	79.3	+ 6.3	+50.8	100	0	− .68	−14.35
September 8	77.0	+ 4.6	+55.4	98	Trace.	− .86	−15.21
September 15	71.6	+ .6	+56.0	90	.68	− .28	−15.49
September 22	55.0	−14.1	+41.9	86	.45	− .46	−15.95
September 29	73.4	+ 7.7	+49.6	93	.24	− .44	−16.39
October 6	59.9	− 2.9	+46.7	90	.01	− .43	−16.82
October 13	61.1	− .9	+47.6	85	.99	+ .70	−16.12
October 20	55.9	− 1.4	+46.2	79	Trace.	− .22	−16.34
October 27	63.3	+ 8.6	+54.8	84	.07	− .23	−16.57

EFFECT OF IRRIGATING STRAWBERRIES, COLUMBIA, MO.

Relative humidity, with departure from normal, at Columbia, Mo., during season of 1901.

Month.	Humidity.	Departure.	Month.	Humidity.	Departure.
	Per cent.	*Per cent.*		*Per cent.*	*Per cent.*
April	60.7	− 4.1	August	52.9	−18.3
May	59.0	−10.8	September	59.3	−13.5
June	56.7	−16.0	October	64.6	− 5.1
July	47.4	−23.4			

IRRIGATION OF STRAWBERRIES.

The matted-row system of growing strawberries is the common one in Missouri, and the strawberries used in this experiment were grown in this manner. The rows are 4 feet apart and originally the plants were approximately 14 inches apart in the row, but had been allowed to fill the spaces between so as to form a solid mat of plants from 12 to 18 inches wide, leaving a vacant space between the rows about 30 inches wide. In these vacant spaces water was run through furrows about 6 inches deep under a uniform flow. At the lower end of the irrigated plat a cross ditch carried the surplus water away, preventing the wetting of the check plats.

The portion of the strawberry field of the station under experiment embraced 6 rows about 200 feet in length, each row being a separate variety, and including some of the leading sorts grown in the State. The irrigated plat was the central section of these rows, the check plats being at each end. As soon after the application of the water as the ground was dry enough, all of the plats were thoroughly cultivated. Thus, in every respect, with the exception of the irrigation, all plats received precisely the same treatment throughout the season. Water was applied three times—on May 12, July 23, and August 28. The area irrigated was one-eighteenth of an acre, to which was applied a total of 15,000 gallons, or enough to cover the plat to a depth of approximately 10 inches. The water used in all experiments was measured by a Worthington improved meter.

Apparently the application of water on May 12 was too late to influence materially the yield of fruit which was then ripening; and it will be necessary to make further experiments to determine when the water should be applied to prevent the small, unmerchantable berries so common on account of lack of moisture in the latter part of the season.

With a good, thrifty growth of plants in the latter part of the season, the strawberry grower is practically assured of a satisfactory crop the following spring. To ascertain whether artificial irrigation would bring about this vigorous growth, water was applied in July and August as stated above. A comparison of the growth of plants, secured on the irrigated and unirrigated plats, as shown in Pl. LI, affords a definite answer to this question. Only rows A and B, as shown in the illustration, were irrigated.

The season was very disastrous to strawberry plants, many of the old plants dying, and practically no runners being formed under ordinary treatment. The irrigated plants developed strong crowns and undoubtedly stored an abundant supply of food for next year's crop. The strawberry nurseryman, the man whose business it is to supply plants for the commercial strawberry grower, will find in irrigation absolute protection against failure. While it will be necessary to have a record of next season's fruit yield to measure accurately the value of irrigation on this crop, it is clear from the results already obtained that the labor and expense involved in irrigating are insignificant in comparison with the benefits obtained.

IRRIGATION OF BEARING APPLE ORCHARDS.

Twenty-four young, vigorous apple trees just coming into bearing were included in the test and embraced the following standard varieties: Ben Davis, Gano, Jonathan, Missouri Pippin, and Jeniton. They were in rows 25 feet apart each way, on strong land, had been given excellent cultivation ever since they were set out, and were in a vigorous, thrifty condition. In choosing the trees for experiment they were arranged in pairs, having the two trees of each pair as nearly alike in size, form, vigor, quantity and quality of fruit set as possible, one of which was irrigated and the other not. Care was taken to have the irrigated tree far enough away from the unirrigated tree to avoid any effect of the water on the latter.

The water was applied as follows: The soil from the trunk of the tree outward to the ends of the branches was removed to the depth of from 10 to 15 inches, or until many of the larger roots were exposed. The soil around the tree was thoroughly saturated by filling the basin with water. Water was conveyed to the trees through pipes, so as to avoid wetting the soil in the vicinity of the unirrigated trees. When all the water had soaked into the subsoil the surface soil was thrown back around the tree and smoothed over. Water was applied to these trees on August 23 and September 19. The amount of water applied each time was measured by means of a water meter, and amounted to 585 gallons per tree for the season, or the equivalent of a depth of 1.3 inches over the whole area, on the basis of 60 trees to the acre. A careful record was kept of the number and weight of apples that fell prematurely from each tree, and at harvest the apples remaining on the trees were counted and weighed; but so far as we are able to judge from the results, the application of water was made too late to affect the crop this year.

A large number of measurements were made of the length and diameter of the twigs on many of the prominent lateral and upright branches of all the trees at the time the water was applied, but the results are not of practical value. With reference to the foliage, it

was observed that there was a decided difference in the dates when the leaves began to die, the foliage on the irrigated trees remaining green much longer than on the unirrigated ones, thus showing that the period of growth had been prolonged. A heavy frost caused all the leaves to fall about the same time, so that there was no opportunity to observe the difference in the natural shedding of the foliage.

It is perhaps impossible to determine by any means at our command the exact influence of irrigation upon these trees, as it is possible that the increased activity of the vital processes during the severe drought, the formation of new root fibers, the storage of more starch in the young twigs and roots, constitute an advantage to the irrigated trees that will be manifest in the succeeding seasons. Prominent and experienced orchardists maintain that the injuries of such a drought as we have just experienced extend over a number of years, and that trees past the prime of life rarely fully recover. If this be true and this injury can be counteracted by the slight expense of irrigation, the benefits will be very marked.

IRRIGATION OF NURSERY STOCK.

Most of the crop in the nursery experimented with consisted of apple trees grown from grafts planted in the spring. Nine varieties of apples were represented in the planting. The rows were 4 feet apart and the plants from 8 to 12 inches apart in the rows. In the middle of the nursery a block was marked off to be irrigated. This plat extended across 28 rows, included all of the varieties, and represented an average of soil conditions and growth of the field. Adjoining both ends of this block were check plats of unirrigated stock. The land slopes gently toward the north and west; the rows ran north and south. Furrows for irrigating were made with a single shovel plow, as in the strawberries, but as close to the trees as possible on the upper side of the rows, thus leaving one furrow in each space between rows. There were two applications of water—one August 24, consisting of 5,740 gallons, and the second September 23, of 6,800 gallons. The area irrigated was one-eighth of an acre, to which was applied a total of 12,540 gallons of water, equivalent to a depth of 3.7 inches. At the last watering a furrow was run around each row close to the trees, giving two furrows between the rows. As early after each watering as possible a light, toothed cultivator was run between the rows. At the same time the check plats were cultivated.

At the time of irrigating many measurements were made of the growth that had taken place during the season up to that time, and each tree was tagged to mark it for second measurement. On December 10 the trees were measured again, and the results are given in the table following. The nine varieties mentioned were from rows running through both check and irrigated plats. The figures repre-

sent the average growth per tree, both in length and diameter, for each variety made after August 24.

Record of growth of nursery stock due to irrigation.

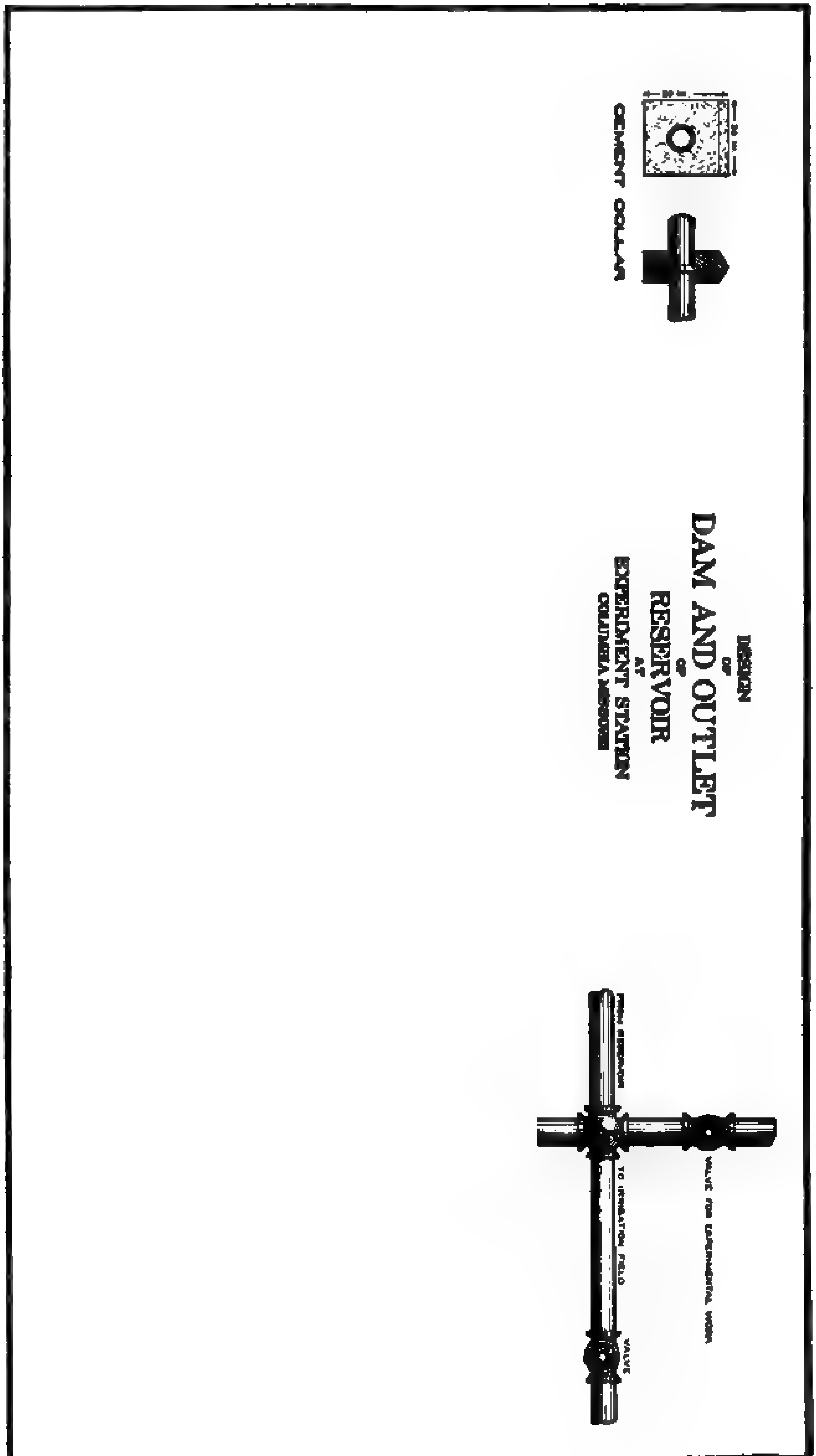
Variety.	Plat.	Length of growth.	Diameter of growth.	Gain in favor of irrigation. Length.	Gain in favor of irrigation. Diameter.
		Inches.	*Mms.*	*Inches.*	*Mms.*
Missouri Pippin	Irrigated	10.3	2.7	7.4	1.3
	Check	2.9	1.4		
Northern Spy	Irrigated	10.1	2.7	5.6	1.2
	Check	4.5	1.5		
Jonathan	Irrigated	9	1.9	5.1	.4
	Check	3.9	1.5		
Grimes Golden	Irrigated	6.2	1.7	4.1	.3
	Check	2.1	1.4		
Ben Davis	Irrigated	6.9	2.3	3.4	.9
	Check	3.5	1.4		
Ontario	Irrigated	3.4	2	3	1.2
	Check	.4	.8		
Clayton	Irrigated	5.6	2	2.8	.7
	Check	2.8	1.3		
Gano	Irrigated	4.1	1	2.8	.1
	Check	1.3	.9		
York Imperial	Irrigated	1.6	1.1	−1.3	−.2
	Check	2.9	1.3		

The above table affords an interesting study of the effects of irrigation on the different varieties. The Missouri Pippin takes the lead in having growth induced by artificial watering. This variety is a rapid grower, or, rather, matures early, and is more precocious in its fruiting habits than any other sort of commercial importance. Just why the others behaved as they did, especially the York Imperial, which made no gain from watering, is problematical.

It is a very desirable thing in young nursery stock, especially apple, that growth be pushed rapidly the first year. The first year's growth usually consists of a straight "whip," which is important because this is the foundation of the branch system of the tree. Trees should have long heads—that is, long central stems—and this is perhaps more necessary for the great fruit region of the south half of Missouri than elsewhere, on account of the character of the soil and the physical aspect of the surface. On the dry ridges and hillsides of this region the trees have a tendency to lengthen their lateral branches without making any upward growth, resulting in trees with small heads and limited bearing surfaces. In the deep, rich soils of other parts of the State this peculiar growth is not noticeable.

Many persons now prefer to plant 1-year-old apple trees if they have attained a certain size, but it is possible to get them of the desired size only in specially favorable seasons. Growers would rather have trees of this age, and are willing to pay almost as much for them as for 2-year-olds, and the nurserymen would be glad to furnish them if they could, as there is always some danger of loss in holding young trees over for a second season's growth in the nursery.

CONSTRUCTING RESERVOIR EMBANKMENT, COLUMBIA, MO.


CEMENT COLLAR
DESIGN
OF
DAM AND OUTLET
OF
RESERVOIR
AT
EXPERIMENT STATION
COLUMBIA MISSOURI
VALVE FOR EXPERIMENTAL WORK
TO IRRIGATION FIELD
VALVE

This season's test showed that it is possible to induce an extra upward growth by watering even very late in the season. However, it is questionable whether it is advisable to irrigate so late in the growing period. If the water could have been applied earlier in the season (in May and June) the root systems would have been stronger and larger, and the linear and diameter growths proportionately increased, and this at the time when the trees need to be pushed in order that they may have an opportunity to better ripen their wood in autumn.

FIG. 9.—Plat of reservoir and land to be irrigated, Missouri Experiment Station.

More extensive experiments were planned, but were not carried out owing to the unfavorable season. The plan includes the construction of a reservoir by damming a draw (fig. 9) on the station farm. The dam (Pls. LII and LIII) was not completed in time to impound a water supply for this season, but will be ready to collect the spring rains in 1903. With this supply of water, more satisfactory results than those reported above should be obtained.

WISCONSIN.

IRRIGATION EXPERIMENTS IN WISCONSIN.

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INTRODUCTION.

It matters little how inherently fertile a field may be, how perfect the condition of the soil as regards texture or tilth, or how congenial the temperature, or abundant the sunshine, if at any stage in the growth of a crop a serious deficiency of soil moisture occurs, there is certain to result a reduction in the yield.

Not all of the rain which falls during the growing season is available to the crops growing upon the ground; some of it is lost by surface and under drainage and still other portions fall in such small quantities at a time that it is practically retained at the surface and lost by direct evaporation without entering the soil. Not only this, but very light rains often do positive injury by destroying the effectiveness of earth mulches, thus causing a loss of water already in the soil with that which has fallen.

During eight years of critical study, from 1894 to 1901, on the influence of moisture on crop production there has not been a single year when irrigation has not very materially increased the yield of one or more crops grown upon a soil reasonably retentive of moisture. It is more often the long intervals without rain, or when the rain falls in small, ineffective amounts, which reduce the yield rather than the small total precipitation during the growing season.

The pages which follow give the details of experiments made in 1901 to determine the returns which may be expected from irrigation in a climate similar to that of Wisconsin on both heavy clay loams and open sandy soils. The experiments were conducted at the experiment-station farm at Madison, Wis., and at Stevens Point, Wis., on the Plover River. Similar experiments have been carried on for a number of years at Madison, and the general results of those experiments are included in the report.

HAY.

The present season was so dry early that it was necessary to water ground sowed to oats and seeded to clover in order to save the clover and secure a stand, and without irrigation the first crop could not have averaged 1.5 tons per acre; but we did cut, through the aid of irrigation, from 4.2 acres, 20.59 tons of hay, or substantially 5 tons per acre, containing 85 per cent dry matter. The actual yields from the several plats expressed in tons per acre are given in the following table:

Yield per acre of hay under irrigation at the station farm at Madison, Wis.

Crop.	Plat 1, oats seeded to clover.	Plat 3, oats seeded to clover.	Plat 4, clover.	Plat 8, alfalfa.
	Tons.	*Tons.*	*Tons.*	*Tons.*
First	3.153	3.483	2.626	2.108
Second	1.770	1.272	1.034	1.280
Third	....	....	1.240	1.074
Fourth	....	....	....	.673
Total	4.923	4.755	4.900	5.135

Nor is this an exceptional yield, for the average of the past six years has been as follows:

Mean yield per acre of hay containing 15 per cent of moisture on the station farm at Madison, Wis., 1896–1901.

Year.	Tons.	Year.	Tons.
1896	4.044	1900	4.581
1897	4.434	1901	4.908
1898	4.031		
1899	4.242	Mean	4.373

The average rainfall for the growing season, April 1 to September 15, during these years has been 15.7 inches, and yet irrigation for hay has increased the yield, on the average, not less than 2.5 tons per acre. It is clear from these results that with irrigation it is possible on only moderately fertile soil to maintain an average yield of 4 tons of hay per acre instead of 1.158 tons, given by the Tenth Census as the average for thirteen States in the humid region.

CORN.

The yields of corn this season on irrigated and unirrigated ground, treated alike otherwise and in only moderate condition of fertility, are as follows:

EFFECT OF IRRIGATION ON CORN, MADISON, WIS.

Yield of corn per acre on ground irrigated and not irrigated, at station farm at Madison, Wis., in 1901.

Corn silage containing 30 per cent of dry matter:		
Irrigated	tons..	14.94
Not irrigated	do...	10.74
Gain from irrigation	do...	4.20
Percentage of gain		39.10
Dry matter:		
Irrigated	pounds..	7,754.00
Not irrigated	do...	5,565.00
Gain from irrigation	do...	2,189.00
Percentage of gain		39.30
Ear corn containing 85 per cent of dry matter:		
Irrigated	bushels..	65.30
Not irrigated	do...	30.14
Gain from irrigation	do...	35.16
Percentage of gain		116.60

There is thus a gain of 4.2 tons of silage, 35.16 bushels of ear corn, and 2,189 pounds, or 1.09 tons, corn fodder per acre due to irrigation.

The irrigation of corn has been tested eight consecutive years. The table given below shows the difference in yield of dry matter per acre of corn irrigated and not irrigated on ground otherwise similar at the station farm at Madison, Wis., from 1894 to 1901.

Yield of corn per acre on ground irrigated and not irrigated, at the station farm, Madison, Wis., 1894–1901.

Year.	Irrigated.	Not irrigated.	Gain.	Percentage of gain.
	Pounds.	*Pounds*	*Pounds.*	*Per cent.*
1894	10,595.50	7,758.75	2,836.75	36.5
1895	10,586.50	2,766.66	7,819.84	282.6
1896	10,205.78	8,071.50	2,134.28	26.4
1897	11,314.75	8,292.25	3,022.50	36.4
1898	9,817.50	....	....	....
1899	10,990.00	7,985.00	3,005.00	37.6
1900	11,330.00	11,056.50	273.50	2.4
1901	7,754.00	5,565.00	2,189.00	39.3
Average	10,324.25	7,356.52	3,040.12	41.3
Tons of silage containing 30 per cent dry matter.	17.2	12.261	5.067	41.3

From this table it is clear that there has been but one year in eight when the rainfall was such as to permit maximum yields of corn to be produced, and that the application of water has given a mean gain of 5.067 tons of silage per acre. Plate LIV shows the differences in the crops of corn as they appear to the eye in the field. We have not each year determined the difference in the yields of ear corn under the irrigated and not irrigated conditions, but whenever this has been done

there has been a much higher percentage of increase than when the comparison is made on the total dry matter. The average increase of ear corn per acre for 1897 and 1901 was 26.95 bushels per acre when the mean not irrigated yield was 34.57 bushels, and this latter figure is slightly higher than the average yield for Illinois, Indiana, Iowa, Kansas, Maine, Michigan, Missouri, Minnesota, New York, Ohio, Pennsylvania, Vermont, and Wisconsin as given in the Tenth Census, that being 34.38 bushels per acre.

From the data here presented, it is safe to conclude that well-managed irrigation in climates like that of Wisconsin may increase the yield of corn silage 40 to 45 per cent and that of ear corn from 50 to 60 per cent as a general average.

POTATOES.

On the clay loam of the station farm irrigation has had a notable effect in increasing the yield, as the results given below attest. Plats 2 and 7 were a clover sod plowed in the spring and manured with fresh stable manue at the rate of 20 tons per acre, while plat 10 had been fallow in 1899, but produced a heavy crop of corn in 1900—over 6 tons of dry matter per acre and 100 bushels ears. The soil is a clay loam.

Yield per acre of irrigated and nonirrigated potatoes at the station farm at Madison, Wis., in 1901.

	Large.	Small.	Total.
Plat 2, clover sod, manured:			
Irrigated .... bushels..	398.24	19.36	417.60
Not irrigated .... do....	194.65	16.42	211.07
Gain from irrigation .... do....	203.59	2.94	206.53
Percentage of gain	104.59	17.90	97.84
Plat 7, clover sod, manured:			
Irrigated .... bushels..	326.05	21.62	347.67
Not irrigated .... do....	185.37	17.80	203.17
Gain from irrigation .... do....	140.68	3.82	144.50
Percentage of gain .... do....	75.89	21.46	71.12
After corn, fallow in 1899:			
Irrigated .... bushels..	359.21	26.29	385.50
Not irrigated .... do....	224.74	23.56	248.30
Gain from irrigation .... do....	134.47	2.73	137.20
Percentage of gain	59.83	11.58	55.21
Average—			
Irrigated .... bushels..	361.17	22.42	383.59
Not irrigated .... do....	201.59	19.26	220.85
Gain from irrigation .... do....	159.58	3.16	162.74
Percentage of gain	79.16	16.40	73.69

From this table it appears that the mean yield under the natural rainfall conditions was 201.59 bushels per acre of merchantable tubers, but that irrigation increased that yield to 361.17 bushels, a gain of 159.58 bushels per acre, or 79 per cent. Pl. LV shows the differences of irrigated and not irrigated potatoes at Madison, Wis., in 1896 and 1901.

DIFFERENCE IN YIELD OF POTATOES ON IRRIGATED AND UNIRRIGATED LAND AT MADISON, WIS.

The mean yields of merchantable potatoes during the past six years are given in the following table:

Mean yield per acre of merchantable tubers on the station farm at Madison, Wis., from 1896 to 1901.

Year.	Irrigated.	Not irrigated.	Gain.	Percentage of gain.
	Bushels.	*Bushels.*	*Bushels.*	*Per cent.*
1896	301.0	210.8	90.2	42.7
1897	333.6	212.3	121.3	57.1
1898	178.8	163.8	15.0	9.1
1899	307.3	174.9	132.4	75.7
1900	328.2	343.4	−15.2	−4.4
1901	361.2	201.6	159.6	79.1
Average for six years	301.7	217.8	83.9	38.5

The mean difference in favor of irrigation as given in this table is 83.9 bushels per acre, or 38.5 per cent.

INCREASE OF YIELD DUE TO IRRIGATION ON SANDY LANDS.

Such results as have been cited regarding the increase in yield of such crops as corn, hay, and potatoes on moderately fertile soil of good water capacity, have led the writer to hope that similar methods applied to the lighter and more sandy soils of the humid portions of the United States might render them sufficiently productive to meet the cost of irrigation and thus enable comfortable homes to be built and maintained on them.

A series of experiments has been planned to extend over not less than two years to ascertain what increase of yield may be secured through irrigation on sandy lands, and also to ascertain if moderate fertilization unaided by irrigation can be made to pay. The work was undertaken on the farm of Mr. George H. Patch, at Stevens Point, Wis., Mr. Patch having already made some effort to establish an irrigation plant there but without success in perfecting it sufficiently to secure results.

THE SOIL AND LOCATION.

The piece of land selected lies about 33 feet above the Plover River and is a part of an old glacial overflow plane into which the present stream has cut its way. The soil is a coarse yellowish sand, having an effective diameter of grains at the surface of about 0.03 millimeter, but increasing in coarseness downward so as to be extremely open and leachy. The effective diameter of the sand grains at the depth of 8 to 16 inches is as great as 0.09 millimeter; but a clearer notion of the openness of the soil is conveyed by the statement that the furrows between four potato rows 3 feet apart and 450 feet long will absorb 80 cubic feet of water per minute.

The general character of the native vegetation on this soil is shown in the background of Pl. LVI. It is a thin growth of stunted black oak and jack pine, with a few blueberries growing among a scanty, thin, short grass.

THE IRRIGATION PLANT.

The water is supplied to the field by a No. 4 centrifugal pump driven by a vertical gasoline engine of about 12 effective horsepower. These are installed in a pump house, the pump setting 6 feet above the water supply and lifting the water about 33 feet through 150 feet of 6-inch lapweld iron pipe, the pump being set and the pipe bent so as to avoid all elbows. The water is brought from the river to the pump through a line of 15-inch sewer tile laid at the level of the bottom of the Plover River, with a fall toward the pump of 6 inches in 270 feet.

The water was conveyed to the field through a hose made of 36-inch duck sewed into long tubes about 11 inches in diameter, and which cost, made up, about 5 cents a running foot. The hose in use, filled with water, is shown in Pl. LVI. Lengths of this hose are coupled by means of a galvanized iron band or hoop inserted in the end of one piece, while the end of the other is drawn over it and secured with a puckering string. This means of distributing the water is not satisfactory, but was used because it had been provided before these experiments were undertaken. The most serious objection to the hose is the heavy seepage which takes place from it unless it is silted up with mud or the cloth is filled with some waterproof material. Mr. Patch was able to greatly reduce the seepage by stirring up the muck of the river bottom for a few minutes and letting this be pumped through the hose until its pores became silted up. The duck hose can be used only where there is little or no pressure except that of the friction head to withstand. To carry the hose through a sag as small as a foot produces heavy seepage, and one as great as 2 to 2.5 feet is liable to split the hose. To avoid these difficulties an embankment was constructed, and the hose is carried on the embankment.

To take the water out for distribution in the furrows, one or more sections of the hose are provided with short side-delivery nipples, made of the same material and sewed in at suitable intervals. These may be partly or completely closed by means of a string threaded through a loop stitched to the nipple, thus regulating the amount of water delivered at any point.

The life of such a hose as this is very short—not more than three or four years at the outside—and it deteriorates very rapidly if left upon the ground a short time in a damp condition.

The method of measuring the rate of pumping was to allow the pump to discharge into a tank holding 277 cubic feet, and note the time required to fill it. The rating was made usually at the close of the watering of each plat, and the length of time the pump had been running was used with the rating to ascertain the amount of water pumped. The gasoline used was measured by the change of level in the supply tank, using a micrometer reading to thousandths of an inch.

DISTRIBUTING WATER FROM 12-INCH CANVAS HOSE, STEVENS POINT, WIS.

IRRIGATING STRAWBERRIES.

IRRIGATED AND UNIRRIGATED STRAWBERRIES.

PLAN OF CROP EXPERIMENTS.

The work with the crops has been planned to test the influence of both fertilizing and watering. The area under experiment this year was about 15 acres, and this was divided into ten plats, as represented in fig. 10. Plat 1 was subdivided into five subplats, three of which were given farm-yard manure at the rate of 9.68 tons per acre, the

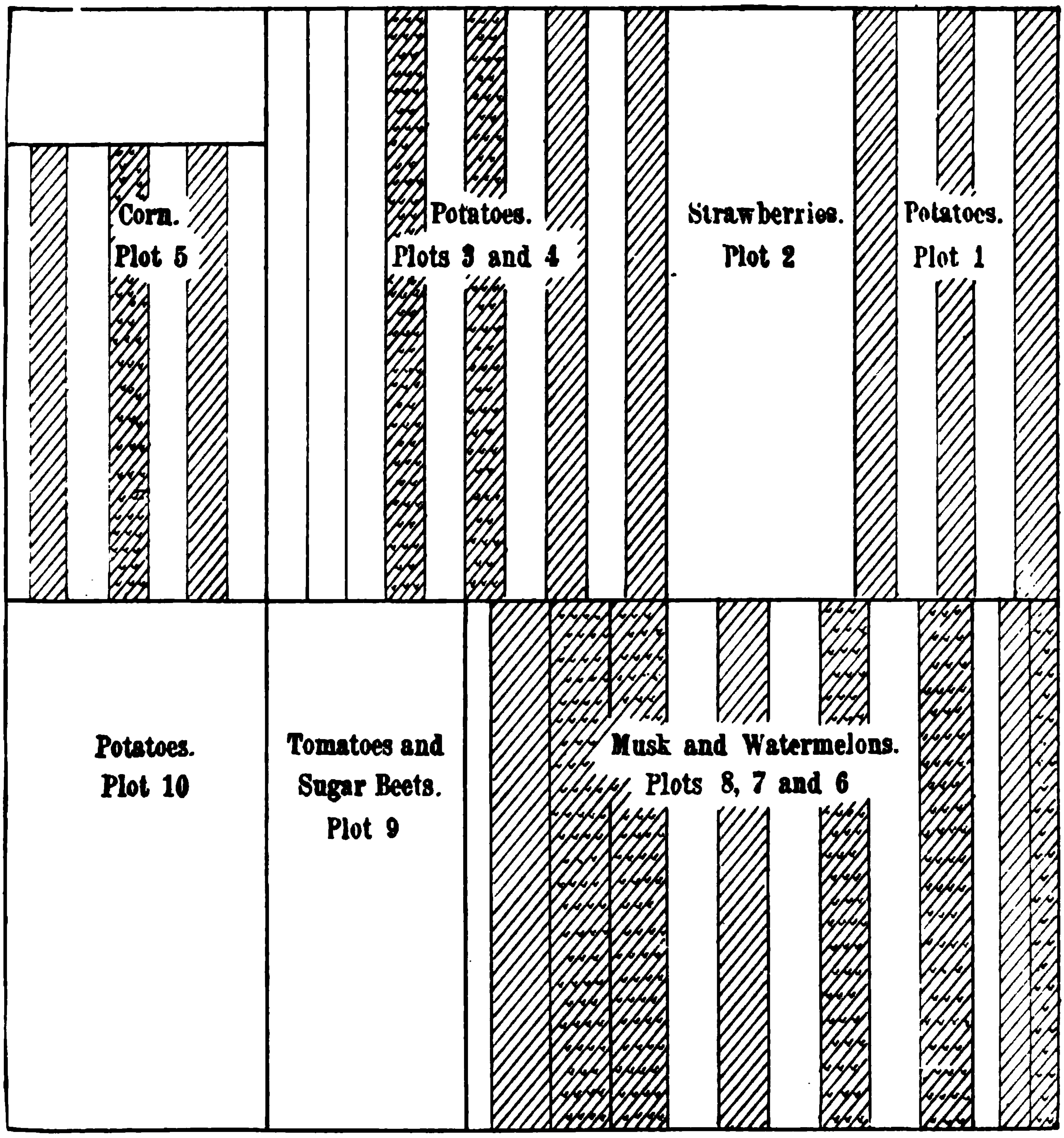

FIG. 10.—Plat of experiment field, Stevens Point, Wis.

manured subplats being those hatched in the diagrams, while the unshaded strips were not manured. Each subplat is 30 feet wide and carried ten rows of potatoes, five of which were irrigated and five not irrigated.

Plat 2 is in strawberries, most of which were set in the spring of 1901. The larger portion of the plat has been irrigated. The plants have made a good growth and promise a fair crop of berries in 1902. There has been no difference so far as manuring is concerned. Pls. LVII and LVIII give a good idea of the condition of the vines in

August, and show clearly the effect on the irrigated as compared with the not irrigated vines.

Plats 3 and 4 were treated together and divided into ten subplats, two of which were manured at the rate of 9.68 tons per acre, and two others at the rate of 19.36 tons per acre, these being represented by the V-shading. Each of these subplats and those not manured are 30 feet wide and planted to ten rows of potatoes, five of which were irrigated and five not irrigated.

Plat 5 was planted to corn, after being subdivided into 6 subplats 30 feet wide, 3 of which were manured and 3 not. The manured subplats received 8.3 and 16.6 tons per acre, the V-shaded areas receiving the heavier dressing; one-half of each subplat was irrigated and the other not.

Plats 6, 7, and 8 were planted to melons in subplats, as represented in the diagram (fig. 10), the shaded strips showing where the manure was applied, and the V-shaded areas showing those given the double dressing, the rates being 12.1 and 24.2 tons per acre. The melons, like the other crops, were part of them irrigated and part not.

Plats 9 and 10 have failed this year to give results on account of a sand storm killing the tomato plants and the sugar beets on plat 9 just after transplanting, and the seed potatoes proving to be of poor quality on plat 10.

The manure used on all the plats was a poor quality of horse manure, containing a high percentage of marsh-hay bedding. It was hauled during the winter and stacked in the field, spreading each load over the whole pile, which was in the form of a long, narrow flat stack. The object of this form of stacking was to secure a more uniform quality of manure to apply to the several subplats. In applying the manure to the field in the spring the wagon was loaded always from one end of the stack, taking manure from the whole width and depth of the pile, thus making each load a full cross section.

YIELDS OF CROPS UNDER THE DIFFERENT CONDITIONS.

PLAT 1, POTATOES.

Plat 1 was planted May 24 to early Ohio potatoes, in rows 3 feet apart, with hills 2 feet apart in the row. The cold, backward spring made all crops late in starting, and the large number of Colorado potato beetles made it necessary to use Paris green four times on the vines. Toward the end of August the vines were struck with "tip-burn," which closed the growing season prematurely, affecting the vines not irrigated soonest and most severely. The last cultivating was done June 29 and the rows were furrowed for irrigation July 8. The plat was irrigated as a whole and separate irrigations were given the subplats, as shown below, the object being to ascertain how often it would be desirable to apply water to soils having such small water capacity.

EVAPOROMETER AND RAIN GAUGE.

Irrigation of plat 1, planted to potatoes.

Date of irrigation.	Depth of water applied to whole plat.	Depth of water applied to subplats A, C, E.	Date of irrigation.	Depth of water applied to whole plat.	Depth of water applied to subplats A, C, E.
	Inches.	*Inches.*		*Inches.*	*Inches.*
July 12	6.36	6.36	Aug. 12		2.18
July 19		2.00	Aug. 19	1.91	1.90
July 23	1.94	1.94	Total	11.81	17.92
July 29		1.94			
Aug. 5	1.60	1.60			

The rainfall from May 1 to and including September 20 is given in the table which follows, as measured by Prof. G. E. Culver, of Stevens Point Normal School, and by the self-recording evaporometer and rain gauge shown in Pl. LIX, the latter instrument not being set in place until July 15.

Rainfall record for Stevens Point, Wis., from May 1 to September 20, 1901.

Date.	Rainfall.	Date.	Rainfall.	Date.	Rainfall.
	Inches.		*Inches.*		*Inches.*
April 16	0.52	June 11	0.35	August 22	0.200
April 17	.38	June 13	.37	August 26	.277
May 1	.13	June 16	.02	August 29	.044
May 10	.20	June 22	.50	September 9	.711
May 21	.12	June 28	.20	September 10	1.660
May 22	1.08	June 29	.55	September 11	.077
May 23	.30	July 4	2.20	September 12	.583
May 24	.06	July 5	.15	September 14	.111
May 30	.15	July 17	.34	September 15	.244
June 5	.66	July 25[a]	.655	September 19	.066
June 6	.07	July 26	.044	September 20	.022
June 10	.15	August 9	.511		

[a] From this date the rainfall was measured by the self-recording evaporometer placed in the field.

The total water received by this plat is given below.

Total depth of water received from rainfall and irrigation by plat 1.

	Not irrigated.	Irrigated once in about 13 days.	Irrigated once in about 6 days.
	Inches.	*Inches.*	*Inches.*
Rainfall, May 1 to July 11	7.260	7.260	7.260
Rainfall, July 12 to September 20	5.495	5.495	5.495
Irrigation	0.000	11.810	17.920
Total	12.755	24.565	30.675

It was learned through the soil moisture studies, given later, that the first irrigation was made too heavy and that practically not more than 1 to 2 inches can be applied at one time without leaching this open soil and wasting water and plant food. The amount of water consumed in making the crop should, therefore, be reduced 4.361 inches below the amounts stated above. When this reduction is made the water used stands—

	Inches.
Not irrigated	12.755
Irrigated once in thirteen days	20.204
Irrigated once in six days	26.314

The yields of potatoes from this plat given on the basis of watering and manuring are as follows:

Yield per acre of potatoes on plat 1.

Items.	Merchantable.	Small.	Total.
Manured:			
Irrigated once in 6 days .... bushels..	143.75	8.83	152.58
Not irrigated .... do....	80.91	7.84	88.75
Gain from irrigation .... do....	62.84	.99	63.83
Percentage of gain	77.6	12.6	71.9
Not manured:			
Irrigated once in 13 days .... bushels..	113.94	11.09	125.03
Not irrigated .... do....	78.65	8.80	87.45
Gain from irrigation .... do....	35.29	2.29	37.58
Percentage of gain	44.8	26.0	42.9
Gain from manuring alone .... bushels..	2.26	−.96	1.30
Percentage of gain	2.8	−10.9	1.4
Gain from manuring and irrigation .... bushels..	65.10	.03	65.13
Percentage of gain	82.7	.3	74.4

In selecting only those plats which were manured as the ones which should be irrigated double the number of times that the rest were irrigated a mistake was made, so that it is not possible to show the effect of the greater frequency of watering unmodified by the manure. As it is, the table shows that (1) when irrigation was not practiced the manure only added 2.26 bushels per acre to the yield; (2) but when the ground was watered once in thirteen days and not manured the yield was increased 35.29 bushels per acre; and (3) when manured and irrigated once in six days there was an increase in yield of merchantable potatoes of 62.84 bushels per acre over the ground manured but not irrigated, and of 65.10 bushels per acre over that not manured and not watered. With these figures standing, the conclusion appears warranted that this land needs water more than manure when potatoes are the crop to be raised. Manure alone increased the yield 2.26 bushels per acre; water alone increased the yield 35.29 bushels per acre; but water and manure combined increased the yield 65.1 bushels per acre, when only 9.68 tons of manure were applied.

PLATS 3 AND 4, POTATOES.

These two plats were, in a measure, worked together as a single experiment. The seed used was of the Burbank type, and the planting was done June 6 to 8 in rows 3 feet apart and in hills 2 feet apart in the row. The vines were killed by frost October 3, a little too early for maximum yields to be secured, but except this, everything was favorable for a fair crop. The bugs interfered somewhat and the vines were treated with Paris green June 26, July 2, July 9 and 10, and again July 26 and 27.

In fitting these plats for the first irrigation, which was done July 15, only the rows to be irrigated were furrowed, the plats not irrigated being given flat culture throughout the season. Both plats were watered the same number of times and the dates of each irrigation, together with the amounts of water added, follow:

Depth of water applied to plats 3 and 4, planted to potatoes.

	Inches.
July 15	4.596
July 23	2.943
August 6	2.010
August 19-20	2.580
August 27	1.620
September 5	1.955
Total	15.704
Rainfall June 5 to September 20, inclusive	10.715
Total water received	26.419

The yields secured from plat 3 are given numerically in the table which follows, and the actual difference in the yields is shown strikingly in Pl. LX.

Yield per acre of potatoes on plat 3 on the basis of manuring.

Items.	Merchantable.	Small.	Total.
Not manured ... bushels	87.74	17.37	105.11
Manured, 9.68 tons per acre ... do	98.22	14.68	112.90
Manured, 19.36 tons per acre ... do	109.47	18.38	127.85
Gain from manuring, 9.68 tons per acre ... do	10.48	−2.69	7.79
Percentage of gain	11.9	−15.4	7.4
Gain from manuring, 19.36 tons per acre ... bushels	21.73	1.01	22.74
Percentage of gain	24.8	5.8	21.6

From this table it appears that the 19.36 tons of manure has increased the yield of merchantable potatoes 21.73 bushels per acre, or 24.8 per cent, while the 9.68 tons increased the yield 10.48 bushels per acre, or 11.9 per cent.

Comparing the yields of plat 3 on the basis of the amount of water applied to the ground the results stand as follows:

Yield per acre of potatoes on plat 3 on the basis of the water applied.

Items.	Merchantable.	Small.	Total.
Rows not irrigated ... bushels	69.96	16.48	86.44
Rows irrigated on one side (18.6 inches) ... do	107.32	17.49	124.81
Rows irrigated on both sides (26.419 inches) ... do	118.84	15.73	134.57
Gain from irrigation on one side ... do	37.36	1.01	38.37
Percentage of gain	53.4	6.1	44.3
Gain from irrigation on both sides ... bushels	48.88	−.75	48.13
Percentage of gain	69.9	−4.5	55.6

From these data it appears that the 26.45 inches of water is associated with a yield of 48.88 bushels per acre larger than that due to the natural rainfall of 10.715 inches, or an increase of 69.9 per cent, while that associated with the 18.6 inches is 37.36 bushels per acre larger than that due to the natural rainfall of 10.715 inches, or an increase of 53.4 per cent.

If now the yields are compared on the basis of the heavy fertilization with the different rates of watering, and the medium fertilization with the different rates of watering, we get the results given in the following table:

Yields per acre of potatoes on plat 3 compared on the basis of fertilization and watering.

Manuring and watering.	Merchantable.	Small.	Total.
Manure, 19.36 tons per acre:	*Bushels.*	*Bushels.*	*Bushels.*
Watered to a depth of 26.419 inches	135.11	17.75	152.86
Watered to a depth of 18.6 inches	117.50	17.21	134.71
Watered to a depth of 10.715 inches (rainfall)	75.82	20.17	95.99
Manure, 9.68 tons per acre:			
Watered to a depth of 26.419 inches	123.35	13.51	136.86
Watered to a depth of 18.6 inches	108.18	16.31	124.49
Watered to a depth of 10.715 inches (rainfall)	63.12	14.22	77.34
No manure:			
Watered to a depth of 26.419 inches	98.07	15.93	114.00
Watered to a depth of 18.6 inches	96.26	18.96	115.22
Watered to a depth of 10.715 inches (rainfall)	68.10	18.01	86.11

From this set of data it appears that if three farmers are manuring their land at the rate of 19.36 tons per acre and one is watering both sides of the rows to a depth of 15.704 inches for the season, another irrigates every other row only, making an average depth of 7.89 inches, while a third depends upon the rainfall, the man who waters every row gains thereby 59.29 bushels of merchantable potatoes per acre, and the man who waters every other row gains 41.68 bushels per acre over one not irrigating. On the other hand, if the men are manuring at the rate of 9.68 tons per acre, the man who gives the full watering gains 60.23 bushels per acre, and the one watering every other row increases his yield 45.06 bushels per acre. Or, again, if three other men are farming this type of land without manure, the one who gives full irrigation gains 29.97 bushels per acre, and the one who waters every other row gains 28.16 bushels per acre.

But if comparison is made between the land which is neither watered nor manured and the others, heavy manure and full irrigation give a gain of 67.01 bushels per acre; heavy manure and half irrigation give a gain of 49.40 bushels per acre; light manure and full irrigation give a gain of 55.25 bushels per acre; and light manure and half irrigation give a gain of 40.08 bushels per acre.

In the above comparison only data of plat 3, whose entire product has been shown in Pl. LX, have been considered. When the entire

DIFFERENCE IN YIELD OF POTATOES ON IRRIGATED AND UNIRRIGATED LAND, STEVENS POINT, WIS.

available product of the 3 acres is tabulated in the same way the results stand as follows:

Yield per acre of potatoes on plats 1 and 3 and 4 compared on the basis of fertilizing and watering.

Manuring and watering.	Merchantable.	Small.	Total.
Manure, 19.36 tons per acre:	*Bushels.*	*Bushels.*	*Bushels.*
Watered to a depth of 26.419 inches	148.63	17.54	166.17
Watered to a depth of 18.6 inches	130.27	18.69	148.96
Watered to a depth of 10.715 (rainfall)	75.35	19.63	94.98
Manure, 9.68 tons per acre:			
Watered to a depth of 26.419 inches	123.35	13.51	136.86
Watered to a depth of 18.6 inches	108.18	16.31	124.49
Watered to a depth of 10.715 inches (rainfall)	63.12	14.22	77.34
No manure:			
Watered to a depth of 26.419 inches	103.13	16.30	119.43
Watered to a depth of 18.6 inches	98.54	19.70	118.24
Watered to a depth of 10.715 inches (rainfall)	75.19	17.24	92.43

Using these data for a set of comparisons similar to those just made for plat 3, it appears that if three farmers are manuring these sandy lands at the rate of 19.36 tons per acre, the one who is watering to a depth of 15.704 inches for the season gains thereby 73.28 bushels of merchantable potatoes per acre; and the man who irrigates only every other row gains 54.92 bushels per acre over the one who depends simply upon the rainfall. On the other hand, if the men are manuring at the rate of 9.68 tons per acre, the one who gives full irrigation gains 60.23 bushels per acre and the one who irrigates every other row gains 45.06 bushels per acre. Again, if the three men are farming this type of land without manure, the one who gives full irrigation gains 27.94 bushels per acre, while the one who waters only one side of each row gains 23.35 bushels per acre.

If comparison is made with the man who neither waters his sandy land nor manures it, heavy manure and full irrigation give a gain of 73.44 bushels per acre; heavy manure and half irrigation give a gain of 55.08 bushels per acre; light manure and full irrigation give a gain of 48.16 bushels per acre; and light manure and half irrigation give a gain of 32.99 bushels per acre.

PLAT 5, CORN.

This plat was manured at two rates, 16.6 and 8.3 tons per acre, with unmanured subplats as checks, and was planted to a variety of small white flint corn May 31 and June 1 in rows 3 feet apart and in hills 4 feet apart in the row. From September 7 to 12 the corn was cut and shocked and allowed to stand and dry until October 4, when it was husked and the air-dry weights determined.

In fitting the plat for irrigation only the subplats watered were furrowed, the subplats not irrigated being left flat, and no cultivation was given after the first watering, which was given July 12.

The dates of irrigation and the amounts of water applied to this plat are as follows:

Depth of water applied to corn in plat 5.

	Inches.
July 12	7.446
July 24	2.010
August 7	2.399
August 20	2.008
August 28	1.860
Total	15.723
Rainfall June 5 to August 29, inclusive	7.291
Total water received	23.014

It was the original intention to water some of the subplats of this plat more frequently than the rest, but the crop showed such marked inequality of growth that after the first watering on this plan it was discontinued. Subplats A, C, and E, therefore, received one more irrigation than is shown in the table, which was 3.86 inches.

The yields of corn secured from this plat are given in the following table:

Yields per acre of flint corn on plat 5, compared on the basis of fertilizing and watering.

Manuring and watering.	Stalks.	Ears.
Manure 16.6 tons per acre:	*Tons.*	*Bushels.*
Watered to a depth of 23.014 inches	1.95	41.80
Watered to a depth of 12.09 inches	1.44	35.76
Watered to a depth of 7.29 inches (rainfall)	1.03	26.38
Manure 8.3 tons per acre:		
Watered to a depth of 23.014 inches	1.73	42.80
Watered to a depth of 12.09 inches	1.48	37.55
Watered to a depth of 7.29 inches (rainfall)	1.21	28.72
No manure:		
Watered to a depth of 23.014 inches	1.36	32.63
Watered to a depth of 12.09 inches	1.33	31.59
Watered to a depth of 7.29 inches (rainfall)	.99	26.75

Comparing these data as was done with the potatoes, it will be seen that when the full irrigation is given with the heaviest quantity of manure there is an increase of yield over the plat having the same quantity of manure but no irrigation, of 15.42 bushels of ears and 0.92 ton of cornstalks per acre, and when only every other row is watered the increase over the natural rainfall is 9.38 bushels of ears and 0.41 ton of stalks per acre; in the first case a gain of 58.45 and 89.32 per cent, respectively, and in the second 35.55 and 39.81 per cent, respectively.

Then, if the 8.3 tons of manure per acre is being used, the full irrigation increases the yield 14.08 bushels of ears and 0.52 ton of stalks per acre, while the irrigation of every other row increases the yield 8.83 bushels of ears and 0.27 ton of stalks per acre. In the first case there is a gain of 49.02 and 42.97 per cent, respectively, and in the second case 30.74 and 22.31 per cent, respectively.

Where no manure is used the full irrigation increased the yield 5.88 bushels of ears and 0.37 ton of stalks per acre, or 21.98 and 37.37 per cent, respectively, and where only every other row is watered the increase in yield was 4.84 bushels of ears and 0.34 ton of stalks per acre, or a gain of 18.09 and 34.34 per cent, respectively.

If the comparison is made, using as a basis 26.75 bushels of ears and 0.99 ton of stalks per acre, the yields from neither manuring nor watering, the gains for manuring and for watering stand as follows:

Gains per acre on plat 5, planted to corn from both manuring and watering.

Manuring and watering.	Ears.		Stalks.	
	Bushels.	*Per cent.*	*Ton.*	*Per cent.*
16.6 tons of manure and a depth of 23.014 inches of water	15.05	56.26	0.96	96.97
16.6 tons of manure and a depth of 12.09 inches of water	9.01	33.68	.45	45.46
8.3 tons of manure and a depth of 23.014 inches of water	16.05	60.00	.74	74.75
8.3 tons of manure and a depth of 12.09 inches of water	10.80	40.37	.49	49.50

It is clear from these results that when both manure and water are added to these soils the yield of corn is notably increased; but if we compare the yields where only manure or only water is added with the same bases used above, 26.75 bushels of ears and 0.99 ton of stalks per acre, the yields where neither water nor manure was added, we get the following results:

Gains per acre on plat 5, planted to corn, from manuring and from watering.

Manuring or watering.	Ears.		Stalks.	
	Bushels.	*Per cent.*	*Ton.*	*Per cent.*
16.6 tons of manure and no irrigation	−0.37	−1.38	0.04	4.04
8.3 tons of manure and no irrigation	1.97	7.36	.22	22.22
23.014 inches of water and no manure	5.88	21.98	.37	37.37
12.09 inches of water and no manure	4.84	18.09	.34	34.34

From these figures it is clear that what these sandy lands most need is greater frequency of watering. Where only manure has been added the yield has not been increased. There was not moisture enough present in the soil to utilize the manure. But when the soil has its water content increased but with no manure added, the yields were increased 18 and 22 per cent, respectively, of ears, and 34 and 37 per cent, respectively, of stalks, showing that with the water content maintained higher the plant food in the soil was great enough for a fifth to a third larger yield.

PLATS 6, 7, AND 8, MELONS.

The experiments this year with melons have not been satisfactory from the standpoint of investigation. In the first place, a very poor stand was secured, partly because of too deep covering of seed and partly from injury by sand storms; in the second place, several varieties of seed were planted on the same plats; and in the third place, the melons were late in getting started.

In the case of the watermelons the stand was an average of only 43.18 per cent complete, in the Osage muskmelon plat it was an average of only 50.76 per cent, and in the plat of varieties of muskmelons it was an average of only 65.01 per cent complete.

The melons were planted from May 27 to May 29, the watermelons in rows 4.5 feet apart and in hills 9 feet apart in the row. The muskmelons were planted in rows 4.5 feet apart, with the hills 6 feet apart in the row. The first watering was begun on July 17, and the complete record of irrigation is as follows:

Depth of water applied to melons on plats 6, 7, and 8.

	Inches.
July 17	4.22
August 1	3.78
August 13 and 14	2.952
August 26 and 27	1.897
September 3 and 4	1.443
Total	14.292
Rainfall May 30 to September 14, inclusive	10.533
Total water received	24.825

The picking of melons was begun on September 3 and the last were gathered on October 2. The method observed in obtaining the yields was to count and weigh the melons from the several subplats as they were gathered.

The yields of watermelons are stated in the table following.

Yield per acre of watermelons on plats 6, 7, and 8, compared on the basis of manuring and watering.

Manuring and watering.	Actual yield.	Computed yield.
	Pounds.	*Pounds.*
Manure, 24.2 tons per acre:		
Watered to a depth of 24.825 inches	21,345	69,859.5
Watered to a depth of 17.744 inches	26,233	60,150.1
Watered to a depth of 10.533 inches (rainfall)	22,090	55,550.6
Manure, 12.1 tons per acre:		
Watered to a depth of 24.825 inches	17,133	41,880.6
Watered to a depth of 17.744 inches	18,682	37,364.0
Watered to a depth of 10.533 inches (rainfall)	16,240	36,333.5
No manure:		
Watered to a depth of 24.825 inches	14,920	36,471.1
Watered to a depth of 17.744 inches	10,040	23,250.5
Watered to a depth of 10.533 inches (rainfall)	12,826	18,811.4

Comparing these data as was done with corn, the land which is treated with 24.2 tons of manure per acre and has the rainfall supplemented with 14.29 inches of irrigation water has produced a yield 14,308.9 pounds larger than the same manuring with the season's rainfall, or 25.76 per cent; but where the rows were watered only on one side the increase in yield was 4,599.5 pounds, or 8.27 per cent.

On the other hand, where only 12.1 tons of manure were added per acre the yield has increased, with irrigation both sides of the row,

5,547.1 pounds per acre over that with the same amount of manure but the season's rainfall only, or 15.27 per cent; but where the rows were irrigated only on one side the increased yield was 1,030.5 pounds, or 2.84 per cent. Again, where the ground was not manured the irrigation both sides of the row increased the yield 17,659.7 pounds over that of the ground not irrigated, or 93.87 per cent; and where the rows were irrigated on only one side the yield was increased 4,439.1 pounds, or 23.59 per cent, over that of the ground not irrigated.

The yield of watermelons on the manured ground and on the unmanured ground which was irrigated was thus a fair crop, ranging from 34.9 tons on the heavy manuring and full irrigation to 18.2 tons on the unmanured ground where the rows were watered both sides. The average weight of the irrigated watermelons was 11.3 pounds, and the heaviest melon weighed 34 pounds. The average weight of the not irrigated melons was 10.9 pounds and the heaviest was 20 pounds.

The yields of the Osage variety of muskmelons secured under the different conditions are given in the following table:

Yield per acre of Osage muskmelons on plats 6, 7, and 8, compared on the basis of manuring and watering.

Manuring and watering.	Observed.	Computed.
Manure, 24.2 tons per acre:	*Pounds.*	*Pounds.*
Watered to a depth of 24.825 inches	8,586.2	23,612.0
Watered to a depth of 17.744 inches	8,712.0	20,535.4
Watered to a depth of 10.533 inches (rainfall)	7,526.0	17,128.1
Manure, 12.1 tons per acre:		
Watered to a depth of 24.825 inches	9,834.9	18,030.4
Watered to a depth of 17.744 inches	9,849.0	17,568.5
Watered to a depth of 10.533 inches (rainfall)	6,353.0	12,153.5
No manure:		
Watered to a depth of 24.825 inches	5,045.9	9,704.8
Watered to a depth of 17.744 inches	5,069.5	8,484.3
Watered to a depth of 10.533 inches (rainfall)	5,193.0	8,174.1

Comparing these data as was done with the corn and watermelons, it will be seen that the land receiving 24.2 tons of manure per acre and which was irrigated both sides of the row produced a yield of 6,483.9 pounds greater than the ground receiving only the natural rainfall, or a gain of 37.85 per cent due to irrigation. The ground irrigated on only one side of the row gave a yield 3,407.3 pounds greater than the ground not watered, or a gain of 19.89 per cent due to irrigation.

Taking next the subplats manured at the rate of 12.1 tons per acre and irrigated both sides of the row there was a yield of 5,876.9 pounds per acre, or 48.35 per cent greater in favor of irrigation, and the rows watered on only one side produced 5,415 pounds per acre, or 44.56 per cent more than the not irrigated rows with the same manuring.

Again taking the unmanured ground, it will be seen that the rows irrigated both sides gave a yield of 1,530.7 pounds, or 18.72 per cent

greater than the rows not irrigated, while the rows irrigated on only one side gave a yield of 310.2 pounds, or 3.79 per cent greater than where the natural rainfall alone was depended upon.

If the yield on the ground neither irrigated nor manured is used as a basis for comparison, it will be seen that 24.2 tons of manure and full irrigation made the yield 2.9 times greater; 24.2 tons of manure and irrigation on one side made the yield 2.51 times greater; 12.1 tons of manure and full irrigation made the yield 2.21 times greater: 12.1 tons of manure and irrigation on one side made the yield 2.15 times greater.

In the plat of Osage muskmelons there are two subplats of eight and twelve rows, respectively, manured at the rate of 24.2 tons and irrigated on both sides of the row, and one subplat of eight rows similarly irrigated but not manured. A comparison of these yields should show the effect of the manure under irrigation. The manured and irrigated ground gave a mean yield of 22,039.3 pounds per acre, while the ground that was not manured gave with irrigation only 9,069.4 pounds per acre. It thus appears that the manure and water combined increased the yield 2.4 times.

If subplat E receiving 12.1 tons of manure and having five rows irrigated both sides is compared with subplats B and F not manured, each having five rows watered both sides, we shall have the effect of irrigation and this lighter manuring as compared with irrigation and no manure. The mean yield in the first case is 18,030.4 pounds per acre, while that of the latter is only 9,707.8 pounds per acre, and the yield due to the 12.1 tons of manure per acre is 1.86 times that where no manure was used.

If we compare the yields on the ground manured at the rate of 24.2 tons per acre with those on the ground receiving but 12.1 tons per acre, using the results coming from irrigating both sides of the row, they stand 22,825.7 pounds per acre as an average for the former and 18,030.4 pounds per acre for the latter. It is clear that the yields are not proportional to the manure used, the extra 12.1 tons producing a gain of only 4,795.3 pounds per acre, or 26.6 per cent.

The mean weight of the irrigated muskmelons was 2.72 pounds and of the ones not irrigated 2.18 pounds.

COST OF IRRIGATION.

To estimate the cost of irrigation in this experiment, record has been kept of the amount of gasoline used, the time spent in applying the water, the time spent in placing the hose preparatory to irrigation, and the time required to do the furrowing for irrigation.

Referring to fig. 10, showing the arrangement of plats for estimating the cost of irrigation, plats 1 to 5, inclusive, are treated together,

and plats 6 and 8 are treated as one area. In estimating the labor of furrowing we have counted the man and horse as 1.5 labor units at 15 cents per hour per unit.

Cost of irrigation.

Items.	Plats 1, 2, 3, 4, 5.	Plats 6, 7, 8.
Furrowing, at 15 cents per hour	$4.80	$2.70
Placing hose, at 15 cents per hour	1.80	1.50
Distributing water, at 15 cents per hour	5.38	5.10
Gasoline, at 11.98 cents per gallon	15.98	13.31
Total	27.96	22.61
Average cost per acre	6.70	6.59

From this table it appears that the total cost of irrigation, not counting anything for wear and tear, insurance, or interest on money invested, is from $6.59 to $6.70 per acre, or an average of $6.65. This is counting the time of man labor at $1.50 per day and a single horse at 75 cents per day.

The total water pumped during the season was 383,959.34 cubic feet, using in engine and torch 244.5 gallons of gasoline. This is at the rate of 1,570.4 cubic feet of water per gallon of gasoline lifted to the height of 33 feet and discharged through 95 feet of 6-inch lapweld iron pipe without elbows, and with the suction pipe 6 feet long. It thus appears that with the pumping plant used, water can be lifted 33 feet at the rate of 1 acre-inch per 2.312 gallons of gasoline, or at a cost of 27.96 cents when the gasoline costs 11.98 cents per gallon.

PROFITS DUE TO IRRIGATION.

In making the estimates of profits due to irrigation the data given in the table above will be taken as the cost per acre, and nothing will be deducted for insurance, wear and tear, or interest on money invested.

Profits from irrigation per acre as shown by plat 1, planted to potatoes.

Items.	Ground manured.	Ground not manured.
Yield per acre irrigated ... bushels	143.75	113.94
Yield per acre not irrigated ... do	80.91	78.65
Gain due to irrigation ... do	62.84	35.29
Value at 50 cents per bushel	$31.42	$17.64
Cost of irrigation	6.70	6.70
Profit due to irrigation	24.72	10.94
Value at 25 cents per bushel	15.71	8.82
Cost of irrigation	6.70	6.70
Profit due to irrigation	9.01	2.12

Profits from irrigation per acre, as shown by plats 3 and 4, planted to potatoes.

Items.	Manure 19.36 tons per acre.	Manure 9.68 tons per acre.	No manure.
Yield per acre irrigated .... bushels..	148.63	123.35	103.13
Yield per acre not irrigated .... do....	75 35	63.12	75.19
Gain due to irrigation .... do....	73.28	60.23	27.94
Value at 50 cents per bushel	$36.64	$30.11	$13.97
Cost of irrigation	6.70	6.70	6.70
Profit due to irrigation	29.94	23.41	7.27
Value at 25 cents per bushel	18.32	15.05	6.98
Cost of irrigating	6.70	6.70	6.70
Profit due to irrigation	11.62	8.35	.28

Profits from irrigation per acre, as shown by plat 5, planted to corn.

Items.	Manure 16.6 tons per acre.	Manure 8.3 tons per acre.	No manure.
Yield per acre irrigated .... bushels..	41.80	42.80	32.63
Yield per acre not irrigated .... do....	26.38	28.72	26.75
Gain due to irrigation .... do ...	15.42	14.08	5.88
Value at 50 cents per bushel	$7.71	$7.04	$2.94
Cost of irrigation	6.70	6.70	6.70
Profit due to irrigation	1.01	0.34	—3.76

Profits from irrigation as shown by part of plat 6, planted to watermelons.

Items.	Manure 24.2 tons per acre.	Manure 12.1 tons per acre.
Yield per acre irrigated .... pounds..	69,859.5	41,880.6
Yield per acre not irrigated .... do.....	55,550.6	36,333.5
Gain due to irrigation .... do.....	14,308.9	5,547.1
Number of melons computed from mean weight of 11.1 pounds	1,289	499
Value at 10 cents each	$128.90	$49.90
Cost of irrigation	6.59	6.59
Profit due to irrigation	122.31	43.31
Value at 5 cents each	64.45	24.95
Cost of irrigation	6.59	6.59
Profit due to irrigation	57.86	18.36

Profits from irrigation as shown by part of plat 6, plat 7, and part of plat 8, planted to Osage muskmelons.

Items.	Manure 24.2 tons per acre.	Manure 12.1 tons per acre.	No manure.
Yield per acre irrigated .... pounds..	23,612.0	18,030.4	9,704.8
Yield per acre not irrigated .... do.....	17,128.1	12,153.5	8,174.1
Gain due to irrigation .... do.....	6,483.9	5,876.9	1,530.7
Number of melons computed from mean weight of 2.45 pounds	2,646	2,398	625
Value at 2 cents each	$52.92	$47.96	$12.50
Cost of irrigation	6.59	6.59	6.59
Profit due to irrigation	46.33	41.37	5.91

COST OF PUMPING AND THE PROFITS OF IRRIGATION AT MADISON, WIS., 1901.

The pumping plant at the Wisconsin Agricultural Experiment Station consists of an 8-horsepower portable steam engine, with horizontal boiler and a No. 4 centrifugal pump, which draws its water through 113 feet of 6-inch lapweld iron pipe and discharges always to a height of 26 feet through not less than 212 feet of the same pipe, and some of the time through 1,258 feet and 300 feet of 4-inch pipe. Soft coal is used for the engine, and this year the account stands thus:

Cost of pumping at Madison, Wis., 1901.

Total water pumped .... cubic feet..	434,928
Total coal used .... tons..	5.314
Cost of coal at $5 per ton	$26.57
Fuel cost of water per acre-inch	.22

The cost at Stevens Point with gasoline, as given on page 331, was 27.96 cents per acre-inch for a 33-foot lift. This brings the two very close together when allowance is made for the difference in lift, there being only 5 cents in favor of gasoline, assuming the same efficiency of pumping at 33 feet as at 26 feet, which is hardly to be expected.

The amount of ground to which water was applied at Madison this year was a trifle more than 7.26 acres, and the cost of irrigating this area, not counting insurance, wear and tear, or interest on investment, was as follows:

Cost of irrigation at Madison, Wis., 1901.

5.314 tons of soft coal, at $5 per ton	$26.57
22.5 hours fitting ground for irrigation, at 15 cents	3.38
124 hours distributing water and care of engine, at 15 cents	18.60
Total	48.55
Cost of irrigation per acre for the season	6.687

The average yield of hay this season from a little more than 4 acres irrigated was 4.91 tons per acre, while similar land not irrigated did not average more than 1.5 tons. This leaves a gain of 3.41 tons per acre. Hay this season was selling at from $9 to $13 per ton here. Counting the hay at $8, the profits are:

Profits from irrigation of hay, Madison, Wis., 1901.

3.41 tons hay, at $8	$27.28
Cost of irrigation	6.68
Profit per acre due to irrigation	20.60

In the case of corn in 1901 there was a gain of 4.2 tons of silage corn per acre, containing 30 per cent of dry matter, and of 35.16 bushels of 70 pounds of ear corn containing 85 per cent of dry matter. The profits per acre stand:

Profit per acre from the irrigation of corn for ear corn.

Ear corn from irrigated ground, 65.3 bushels, at 50 cents	$32.65
Ear corn from ground not irrigated, 30.14 bushels, at 50 cents	15.07
Gain on ears due to irrigation	17.58
Gain on stalks due to irrigation	.28
Total gain per acre due to irrigation	17.86
Cost of irrigation per acre	6.68
Profit per acre due to irrigation	11.18

Profit per acre from the irrigation of potatoes.

Mean yield of irrigated tubers per acre ... bushels	361.2
Mean yield of tubers not irrigated per acre ... do	201.6
Gain due to irrigation ... do	159.6
159.6 bushels per acre, at 50 cents	$79.80
Cost of irrigation per acre	6.68
Profit per acre due to irrigation	73.12

The mean gain of potatoes for the six years of experiments has been 83.9 bushels per acre, which at 25 cents per bushel makes a gain of $20.97 per acre, which, deducting the cost of irrigation, $6.68, leaves a mean profit per acre of $14.29.

The mean gain of corn silage per acre for the eight years of experiment has been 5.55 tons, which at $2.62 per ton makes a gain due to irrigation of $14.54 per acre, and deducting the cost of irrigation, $6.68, the profit per acre is $7.86.

The mean gain of hay has been not less than 2.5 tons per acre, which at $8 per ton makes a gain of $20 per acre, and deducting the cost of irrigation, $6.68, makes the mean gain not less than $13.32 per acre.

EVAPORATION AT STEVENS POINT.

The installation of apparatus and the stationing of regular observers did not take place early enough to permit securing a record of the rate of evaporation for the whole season. The evaporometer and rain gauge represented in Pl. LIX were not installed until July 15, but from this date forward until October 18 a continuous record was secured. A copy of the week's record beginning July 29 and ending

August 4 is reproduced one-third actual size in fig. 11, and shows the character of the diurnal curves and the actual amount of evaporation which occurred. The instrument is constructed to multiply the evaporation threefold; reducing the record sheet to one-third leaves the evaporation curve natural size so far as the vertical dimensions are concerned.

FIG. 11.—Record sheet for evaporometer.

The total evaporation from July 16 to October 17, inclusive, was 14.064 inches, much more than the rainfall for the corresponding period, and, indeed, more than the mean summer rainfall for the State, which is only about 12 inches.

The mean daily evaporation from July 16 to October 17, inclusive, was 0.15 inch, and the total evaporation by fifteen-day periods, beginning July 16, is shown in the following table:

Total evaporation by fifteen-day periods at Stevens Point, Wis., 1901.

Period.	Inches.	Period	Inches.
July 16 to July 31	3.366	August 30 to September 14	2.144
July 31 to August 15	3.054	September 14 to September 29	1.404
August 15 to August 30	2.543	September 29 to October 14	1.106

The observed evaporation for the whole period follows:

Daily evaporation at Stevens Point, Wis., from July 16 to October 17, 1901.

Day	July.	August.	September.	October.	Day.	July.	August.	September	October
	Inch.	*Inch.*	*Inch.*	*Inch.*		*Inch.*	*Inch.*	*Inch.*	*Inch.*
1		0.167	0.189	0.066	17	0.222	0.189	0.088	0.144
2		.267	.167	167	18	.267	.178	.122	
3		.211	.156	.156	19	.278	.144	.022	
4		.189	.178	.111	20	.300	.233	066	
5		.222	.211	.189	21	.300	.189	.088	
6		.211	.189	.100	22	334	.066	.100	
7		.322	.156	.033	23	.289	.189	.088	
8		.300	.178	.000	24	.233	.211	.178	
9		.055	.066	011	25	.088	.156	.111	
10		.167	088	.083	26	.088	.111	.122	
11		.088	.044	.011	27	.100	.156	.055	
12		.111	.011	056	28	.066	.144	.033	
13		.200	.100	.056	29	.167	.111	077	
14		.222	033	100	30	.367	.244	.044	
15		.239	.077	.111	31	.322	.222		
16	0.267	.233	.211	.100					

Total	14.064
Mean	0.1496

The evaporation during the night has been much larger relatively than was expected. If the period represented by the week's record in fig. 11 is considered, the ratio of the evaporation from 6 p. m. to 6 a. m. to that of 6 a. m. to 6 p. m. is 31 to 58, or, the evaporation during the twelve hours of night is more than half that of the twelve hours of day, 53.45 per cent.

SOIL MOISTURE.

It has been pointed out in the discussion of the yields of crops that the lack of productiveness in the soil at Stevens Point is due more to a deficiency of soil moisture than to a deficiency of plant food.

It is an important matter to know how much available moisture these soils do retain through the intervals from one rain to another in order to understand what reserve the crop has to draw upon, for if this is not likely to be sufficient, then irrigation is certain to be helpful.

AMOUNT OF WATER THE SOILS MAY RETAIN.

In order to determine the amount of water which soils may retain, samples of soil have been taken before irrigation and again at different intervals after putting upon the ground known amounts of water, and the results show what the soil may retain. The results of the first experiment are given in the table which follows. In this case each sample is a composite of five cores each 1 foot long and about 0.75 inch in diameter.

Changes in the water content of sandy soil in plat 3 after the application of 4.59 inches of water by irrigation and after a rainfall of 0.34 inch.

Time of taking sample.	Under row.				Under furrow.			
	First foot.	Second foot.	Third foot.	Fourth foot.	First foot.	Second foot.	Third foot.	Fourth foot.
East end of plat:	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*
Before irrigation	7.70	5.76	3.41	3.25	8.45	4.49	3.19	4.16
1 hour after irrigation	8.05	6.83	4.60	4.82	14.74	10.13	10.61	8.69
18 hours after irrigation	7.41	5.54	3.98	4.05	10.19	6.15	5.15	6.56
42 hours after irrigation	6.72	5.37	3.88	4.32	7.81	4.87	3.95	5.15
66 hours after irrigation	[a] 13.31	6.54	3.94	4.00	10.89	6.38	4.12	5.26
Center of plat:								
Before irrigation	7.64	5.65	3.09	2.88	7.58	4.43	3.14	3.35
1 hour after irrigation	8.10	5.21	2.82	3.62	15.54	10.19	5.54	2.88
18 hours after irrigation	7.81	6.56	4.76	5.54	9.52	6.38	5.76	5.70
42 hours after irrigation	6.89	5.82	3.62	3.68	7.87	4.71	3.84	4.27
66 hours after irrigation	[a] 9.89	6.54	3.95	4.12	10.37	5.99	4.43	3.89

[a] Rainfall of 0.39 inch before this set of samples was taken.

We have not determined the weight of the soils to which the water was applied in this experiment, but it can not be far from 100 pounds for the surface foot and 105 to 110 pounds for the other 3 feet. The amount of water applied was at the rate of 23.87 pounds per square foot. Referring to the table, it will be seen that one hour after applying the water the surface foot under the furrow had gained 6.29

per cent at the east end and 7.96 per cent at the center, or an average of 7.125 per cent. At the above estimate of weight of this soil there is retained in the surface foot 7.125 pounds of the 23.87 applied.

The second foot had gained after watering 5.64 per cent in one case and 5.76 per cent in the other, or an average of 5.7 per cent. At this rate the second foot has retained from 5.985 pounds to 6.27 pounds.

The third foot had gained 7.42 per cent in one case and 2.40 per cent in the other, or an average of 4.91 per cent, which calls for a retention of from 5.155 pounds to 5.401 pounds.

The fourth foot shows no gain after irrigation in one case and only 4.53 per cent in the other, or a mean of 2.265 per cent, which calls for from 2.378 to 2.492 pounds.

The total gain in water content for the upper 4 feet, according to the determinations, is only 20.643 to 21.288 pounds per square foot of surface watered. There was some seepage between the rating tank and the point in the field where the water was applied, and the area to which the water was applied has been considered that covered by the furrows watered plus the rows between them and to the center of each row adjacent to the outside stream of water of each subplat. It is probable that some water has moved outward laterally somewhat beyond this line, but it does not appear probable that much had done so by the end of the first hour, when the first set of samples were taken.

Referring again to the table it will be seen that the increase of water under the row has been nowhere as great as under the furrow. The gain of water under the furrow is less than the amount applied, the deficiency of water being more than 11 pounds, or nearly half the total water applied.

It was after finding this large deficiency of water in the soil after watering that we were led to apply a smaller amount, making a similar study of the water content of the soils before and after irrigation. This was done on plat 1 when only 1.942 inches of water was added. The results are given in the table which follows:

Changes in the water content of sandy soil in plat 1 after the application of 1.942 inches of water by irrigation and after a rainfall of 0.679 inches.

Time of taking sample.	Under row.				Under furrow.			
	First foot.	Second foot.	Third foot.	Fourth foot.	First foot.	Second foot.	Third foot.	Fourth foot.
	Per ct.	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*
East end of plat:								
Before irrigation	5.26	5.15	4.06	3.52	6.34	4.33	3.52	3.89
1 hour after irrigation	5.65	6.10	4.97	5.31	16.77	9.50	9.89	8.46
24 hours after irrigation	6.38	6.64	4.44	4.86	9.57	6.11	4.99	5.02
48 hours after irrigation	9.94	6.16	4.75	4.33	13.71	6.38	5.03	3.95
West end of plat:								
Before irrigation	5.54	6.04	3.84	3.88	7.29	4.87	3.52	4.00
1 hour after irrigation	6.64	7.30	5.53	5.04	14.29	9.76	7.59	6.76
24 hours after irrigation	7.53	6.26	4.50	4.50	10.55	5.21	4.89	5.20
48 hours after irrigation	8.63	5.76	5.21	4.55	13.71	6.59	4.49	4.75

Referring to this table, it will be seen that at both ends of the plat, one hour after watering, there was an increase of soil moisture even in the fourth foot. The mean gain due to watering, as shown by the changes in the percentage of moisture for the 4 feet, both under the row and under the furrow, was from 13.81 to 14.24 pounds per surface foot, while the amount of water added by irrigation was 12.12 pounds. This is, perhaps, as close an agreement as could be expected, because the error of sampling is between 0.06 and 0.07 per cent.

Before the water was applied the 4 feet of surface soil contained from 19.40 to 20.03 pounds per square foot of surface; and by irrigation there was added 12.12 pounds, which should give 31.52 to 32.15 pounds. But twenty-four hours later the results stood:

	Pounds.
Amount of water immediately after irrigation	31.52–32.15
Amount of water 24 hours after irrigation	24.95–25.72
Loss per square foot of surface in 24 hours	6.57– 6.43

From these data it appears that the application of so little as 2 inches of water at once is too much, of this amount only about 1 inch being retained.

It was the plan to take another set of samples forty-eight hours after irrigation, but this was interfered with by a rain of 0.679 inch falling between 5.30 a. m. and 10.30 a. m. Immediately at the close of this rain, nearly all of which had fallen at 9 a. m., another set of samples was taken as indicated in the table and the amount of water found then was 27.76 pounds to 28.53 pounds per surface foot, which is 2.81 pounds more than twenty-four hours earlier; but the amount of water which fell as rain was 3.53 pounds per square foot, so about 0.72 pound per square foot was lost through percolation.

PERCOLATION EXPERIMENTS ON FALLOW GROUND.

After these results had been secured it was decided to make a trial on fallow ground on which a weighed quantity of water was applied to a measured area of 72 square feet in the form of a 6-foot by 12-foot rectangle. Just before applying the water a composite set of samples for each foot in depth was taken close to the outside margin of the plat. The water was then slowly and evenly applied with a sprinkling can and at intervals afterward samples were taken in composite sets of 4 along lines parallel to the sides. The results appear below:

Changes in the water content of fallow ground at different intervals after watering.

Time of taking sample.	Water applied, 0.75 inch.				Water applied, 1 inch.			
	First foot.	Second foot.	Third foot.	Fourth foot.	First foot.	Second foot.	Third foot.	Fourth foot.
	Per ct.	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*
Before irrigation	9.17	5.59	3.16	3.16	10.70	5.36	3.47	3.25
1 hour after irrigation	**13.52**	5.26	3.09	3.16	**14.80**	**6.10**	3.25	2.93
4 hours after irrigation	**12.48**	5.64	2.92	2.99	**13.25**	**7.59**	3.25	3.26
6 hours after irrigation	**12.79**	**6.28**	3.09	3.03	**12.79**	**7.35**	**5.14**	3.25
21 hours after irrigation	**12.23**	**6.82**	**4.00**	3.09	**12.16**	**6.70**	**4.38**	3.47

From this table it will be seen that, beginning with the water content of the amounts at the start and 0.75 inch of water applied, at the end of one hour the water added is still all in the first foot; at the end of four hours some water has entered the second foot, and at the end of twenty-one hours the water in the first foot has decreased, but in both the second and third foot has increased. There is, however, no gain in the fourth foot.

Where 1 inch of water was applied to soil containing 10.7 per cent of water at the start, instead of 9.17 per cent, as in the former case, water reached the second foot at the end of the first hour, the third foot at the end of six hours; but at the end of twenty-one hours the water is still all in the surface 3 feet.

Samples of soil were also taken at different intervals after rainfalls to get the movement of water downward under those conditions. Two sets of these data are presented in the table.

Changes in the water content of soils at different intervals after rains.

Date.	Time after rain.	On fallow ground.				Between rows of corn.			
		First foot.	Second foot.	Third foot.	Fourth foot.	First foot.	Second foot.	Third foot.	Fourth foot.
		Per ct.	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*
Sept. 10.	14 hours after rain of 0.9 inch.	13.25	7.17	3.04	2.82	9.81	2.71	1.88	2.47
Do...	20 hours after rain of 0.9 inch.	12.33	7.11	3.09	2.99	8.46	2.60	1.83	2.46
Sept. 11.	36 hours after rain of 0.9 inch.	11.45	**7.41**	3.20	2.88	8.11	**3.47**	1.99	2.56
Sept. 12.	7 hours after rain of 0.533 inch.	12.22	**8.00**	**4.28**	2.47	11.33	**3.95**	1.26	1.94
Sept. 13.	5 hours after rain of 0.066 inch.	12.34	**8.40**	**5.99**	2.30	9.76	**5.45**	1.94	2.71

From this table it is clear that the rainfall of 1.499 inches covering three days has put a notable quantity of water into the third foot of the more moist fallow ground and into the second foot of the drier corn ground, the bold-face type in the table showing where the increase has occurred. The table also emphasizes how small the normal water content of these soils is and how strong is the tendency for them to leach and to lose both plant food and an excess of water applied to them. It is further clear from all of the data presented that when much more than 1 inch of water is applied at one time to these open, sandy soils percolation is likely to occur, carrying plant food beyond the reach of the roots of the crop growing upon the field.

MOISTURE CONTENT OF THE SOILS DURING THE GROWING SEASON.

At intervals during the growing season the moisture content of the soil of plats 1, 3 and 4, and 5 was determined in 1-foot sections to a depth of 4 feet, both under the rows and between the rows. The determinations were made in such a way as to show the moisture on

the irrigated and not irrigated ground, and on that manured and not manured. These results appear in the table which follows.

Variations in the percentage of soil moisture in the soils of plats 1, 3 and 4, and 5, under the different treatments.

ON IRRIGATED GROUND.

Date.	First foot.		Second foot.		Third foot.		Fourth foot.	
	Between rows.	In row.	Between rows.	In row.	Between rows.	In row.	Between rows.	In row.
Plat 1, potatoes:	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*
July 25[a]	11.34	8.69	7.53	6.21	4.17	4.13	3.67	3.63
August 2	7.23	6.04	5.21	5.38	4.28	3.84	4.11	3.31
August 15	6.81	5.70	4.81	4.92	3.57	3.57	3.46	3.52
September 10	11.00	9.69	5.82	4.98	3.04	3.09	3.36	2.77
Plats 3 and 4, potatoes:								
August 5	6.64	6.49	5.38	5.31	3.09	3.73	3.20	2.82
August 19	5.93	4.44	4.12	4.33	3.15	2.93	3.09	3.58
September 3	5.53	4.28	4.33	3.20	3.25	2.77	2.77	3.09
Plat 5, corn:								
July 13[b]	10.51	7.97	5.91	6.34	3.89	7.29	4.08	6.26
August 6	6.60	6.64	4.12	4.49	2.88	3.05	3.05	3.09
August 16	5.48	5.48	3.36	2.98	2.41	2.14	2.61	2.48
September 6	6.82	5.59	3.78	4.06	2.88	2.36	3.95	3.20

ON GROUND NOT IRRIGATED.

Plat 1, potatoes:								
July 25[a]	10.37	7.41	5.26	4.00	3.09	3.20	2.77	2.93
August 2	6.10	5.38	4.38	4.38	2.88	3.83	2.71	2.30
August 15	5.64	4.86	3.94	4.12	3.20	2.93	2.98	2.56
September 10	11.11	7.65	4.55	5.09	2.93	2.88	2.46	2.30
Plats 3 and 4, potatoes:								
August 5	6.82	6.21	5.16	4.97	2.98	2.82	2.72	2.82
August 19	5.15	4.39	4.33	4.12	2.88	2.56	2.51	2.52
September 3	3.47	3.89	2.57	2.30	1.88	1.99	2.47	2.66
Plat 5, corn:								
July 13[b]	9.33	9.67	5.16	4.27	3.35	3.08	3.35	3.19
August 6	5.53	5.24	4.06	3.05	2.77	2.40	2.48	2.48
August 16	4.00	3.83	2.25	2.52	2.20	1.99	2.57	2.14
September 6	3.95	3.68	2.20	2.41	1.89	1.94	2.57	2.66

ON MANURED GROUND.

Plat 1, potatoes:								
August 2	5.93	4.76	4.38	4.60	3.31	3.20	2.56	2.93
August 15	6.65	5.09	4.33	4.86	2.98	3.52	2.71	3.04
September 10	10.55	8.69	4.44	4.44	2.73	2.88	3.47	2.51
Plats 3 and 4, potatoes:								
August 5	6.82	7.82	4.98	5.21	2.77	3.81	2.60	2.82
August 19	4.76	4.12	3.89	3.52	2.56	2.66	2.52	2.82
September 3	7.70	4.00	3.09	3.31	2.51	2.77	2.92	3.36
Plat 5, corn:								
August 6	5.54	5.09	3.89	3.63	2.36	2.36	2.40	2.40
August 16	3.95	3.47	2.48	2.04	2.04	1.57	1.94	1.89
September 6	5.42	5.16	3.63	4.00	2.66	2.57	4.11	2.82

ON GROUND NOT MANURED.

Plat 1, potatoes:								
August 2	5.48	4.61	3.78	4.07	2.71	2.98	2.48	2.56
August 15	6.09	5.21	4.86	4.44	3.68	3.42	3.20	3.31
September 10	10.07	8.22	5.38	4.07	2.80	2.36	2.41	2.47
Plats 3 and 4, potatoes:								
August 5	6.42	5.85	4.71	5.19	3.09	3.44	2.82	2.74
August 19	5.53	4.44	3.78	3.78	2.82	2.82	2.82	2.66
September 3	4.17	4.33	2.31	2.88	2.57	2.20	3.05	2.93
Plat 5, corn:								
August 6	6.27	5.93	4.06	3.68	2.48	2.30	2.67	2.30
August 16	4.98	4.12	3.09	2.57	1.89	1.89	2.04	2.04
September 6	5.99	5.03	3.68	2.88	2.46	2.82	3.14	2.66

[a] Samples of July 25 taken just after a rainfall of 0.679 inch.
[b] Samples of July 13 taken just after irrigation.

The mean amount of soil moisture in each of the plats for the 4 feet combined and for the whole period has been computed for the irrigated and not irrigated condition and for the manured and not manured condition, and the results appear in the table which follows:

Mean amount of moisture in the surface 4 feet of ground irrigated and not irrigated and manured and not manured, from July 25 to September 10.

Plats.	Irrigated.	Not irrigated.	Manured.	Not manured.
	Per cent.	*Per cent.*	*Per cent.*	*Per cent.*
1, potatoes	5.276	4.097	4.357	4.173
3 and 4, potatoes	4.060	3.508	3.871	3.640
5, corn	4.194	3.475	3.226	3.382
Average	4.5096	3.6933	3.818	3.732
Difference	.8163		.086	

It is remarkable that with the amounts of water added to the irrigated ground there is no larger difference shown in the percentages of soil moisture. Taking the dry weights of the soil under consideration at 100, 104, 107, and 111 pounds per cubic foot for the first to the fourth foot, and the total weight of the surface 4 feet as 422 pounds, the mean difference between the amounts of water on the irrigated ground and the ground not irrigated is 3.607 pounds per square foot or 157,060 pounds per acre.

It should be stated, however, that in taking samples of soil for moisture determinations an effort was made to take the samples just before the time for irrigation and never very soon after watering.

Referring to the manured ground and the ground not manured, it will be seen that the water content averages higher in the manured ground than in that not manured, but the difference is not large and is even reversed in plat 5. A somewhat higher water content on the manured ground is what should be expected from the tendency of the manure to increase the humus.

PROPORTION OF SOIL MOISTURE AVAILABLE FOR CROPS ON THE SANDY LANDS.

Not all the moisture a soil contains is available to a crop. When the film of water investing the soil grains becomes very thin the capillary rate of movement becomes too slow to enable the roots to get enough water for their needs. But the percentage of water in a soil is not alone an index of the thickness of the water film. The coarser the soil grains are in a given type the smaller may be the percentage of water it contains to meet the needs of crops. A heavy red clay, for example, with very small grains may have so large an internal sur-

face for the water to cover that the same thickness of film which gives but 1.1 per cent water in a sandy soil will give to the clay as high as 14.24 per cent and yet to the plant the two soils are equally moist, the plant wilting no quicker in one than in the other.

The very small percentages of moisture which these Stevens Point soils contain should not be understood as indicating that they are extremely dry, judged from the standpoint of plant growth. The samples of soil taken on plat 5, August 16, show the lowest limit of soil moisture to which these soils may fall without serious results on the crop, for at this stage the corn leaves curled badly in the hot part of the day. At this stage the surface 4 feet contained 11.13 pounds of moisture per square foot of surface; the mean amount for the season in the irrigated ground was 19.03 pounds, or 70.98 per cent more, while that in the ground not irrigated was 15.59 pounds, or 40.07 per cent more.

The amount of water in the surface 4 feet of the fallow ground, as given in the table on page 339 for September 13, is the maximum amount which this soil can retain without rapid percolation, and is not far from 30.63 pounds per square foot and is 11.6 pounds higher than the mean amount, 19.03 pounds, found on the irrigated ground. This latter amount is probably as low as the moisture should be allowed to get before another irrigation would be helpful and profitable. If these conclusions are correct, then the best amount of water to apply at one time on these lands would be 11.6 pounds per square foot, or a little more than 2 inches. It is the judgment of the writer, however, that more frequent irrigation for these lands at the rate of 1 to 1.5 inches would render the highest service, if it could be applied uniformly over the surface.

LOSS OF FERTILITY FROM SANDY SOILS BY LEACHING.

In undertaking the demonstration of the desirability of irrigating sandy lands in humid climates, it was anticipated that the application of too much water to these lands might lead to the loss of so much plant food by leaching as to overcome any advantage which might be derived from the irrigation, and because of this possibility it was decided to study the variation and movements of nitrates in these soils as influenced by irrigation.

Samples of soil were taken in the furrows and under the rows before irrigation, and the nitrate content determined by the method described in Bulletin 85 of the Wisconsin Experiment Station. The nitrates were also determined in the samples of soil taken for the soil moisture studies and these results are given in the table which follows.

Variations in the amounts of nitrates in soils of plats 1, 3, and 4 and 5 under the different treatments.

[Parts per million of the dry soil.]

ON IRRIGATED GROUND.

Date.	First foot		Second foot.		Third foot.		Fourth foot.	
	Between rows.	In rows.	Between rows.	In rows.	Between rows.	In rows.	Between rows.	In rows.
Plat 1, potatoes:								
July 25	8.50	9.96	2.40	11.11	1.91	6.93	1.67	4.59
August 2	5.14	8.38	4.09	10.77	12.95	5.87	1.62	3.55
August 15	2.56	4.58	1.63	4.25	1.84	3.27	1.26	3.73
September 10	1.62	9.58	1.77	5.60	1.14	3.71	.63	2.33
Plats 3 and 4, potatoes:								
August 5	5.11	21.35	2.93	14.04	1.37	8.50	2.40	3.64
August 19	3.59	7.07	1.56	9.14	1.43	5.01	1.43	1.34
September 3	1.86	3.89	1.27	3.65	1.20	6.71	1.19	3.02
Plat 5, corn:								
August 6	2.08	4.75	1.39	5.10	1.76	3.31	1.88	1.88
August 16	1.00	2.23	1.06	1.37	.76	2.31	1.11	1.53
September 6	1.43	1.76	1.95	1.61	1.25	2.77	1.21	1.37

ON GROUND NOT IRRIGATED.

Date.	First foot		Second foot.		Third foot.		Fourth foot.	
	Between rows.	In rows.	Between rows.	In rows.	Between rows.	In rows.	Between rows.	In rows.
Plat 1, potatoes:								
July 25	3.83	9.10	5.03	5.30	5.82	4.11	4.21	2.22
August 2	9.33	11.01	2.78	15.04	8.31	5.95	4.66	2.60
August 15	8.22	21.55	11.98	16.62	8.68	6.15	5.47	2.50
September 10	5.84	8.17	10.21	7.35	6.26	5.24	2.55	2.71
Plats 3 and 4, potatoes:								
August 5	16.43	13.95	12.84	14.69	7.07	5.80	2.73	2.84
August 19	14.25	10.19	8.45	9.46	2.78	4.08	1.93	1.64
September 3	8.48	4.61	10.43	13.34	4.11	3.77	1.98	3.00
Plat 5, corn:								
August 6	4.22	4.21	6.00	4.90	2.96	1.87	2.04	2.38
August 16	4.21	4.37	1.86	2.04	1.19	2.65	1.36	1.30
September 6	2.71	4.08	2.99	4.53	1.86	1.86	2.10	2.04

ON MANURED GROUND.

Date.	First foot		Second foot.		Third foot.		Fourth foot.	
	Between rows.	In rows.	Between rows.	In rows.	Between rows.	In rows.	Between rows.	In rows.
Plat 1, potatoes:								
August 2	25.92	17.21	15.98	20.43	8.58	6.62	4.88	3.19
August 15	5.95	8.17	4.51	6.05	4.56	4.36	2.85	3.36
September 10	3.72	7.90	3.59	2.67	3.53	4.38	2.58	2.38
Plats 3 and 4, potatoes:								
August 5	12.38	28.39	10.73	16.36	3.07	2.52	1.70	2.22
August 19	7.67	9.00	5.64	6.31	1.82	4.98	1.81	2.39
September 3	6.25	3.91	7.53	8.12	3.00	5.23	2.45	4.01
Plat 5, corn:								
August 6	2.82	3.50	2.30	2.87	2.15	1.36	1.92	1.13
August 16	3.00	3.00	2.43	3.10	.90	1.06	2.76	.53
September 6	1.64	4.51	1.38	3.21	1.42	1.87	1.73	1.99

ON GROUND NOT MANURED.

Date.	First foot		Second foot.		Third foot.		Fourth foot.	
	Between rows.	In rows.	Between rows.	In rows.	Between rows.	In rows.	Between rows.	In rows.
Plat 1, potatoes:								
August 2	4.34	7.89	8.07	8.07	8.29	5.01	4.53	3.86
August 15	5.31	16.94	5.12	15.52	5.28	6.64	5.25	4.58
September 10	3.70	2.90	1.76	7.84	1.64	2.94	2.09	2.43
Plats 3 and 4, potatoes:								
August 5	6.63	11.77	9.65	14.03	4.68	9.28	3.07	3.98
August 19	11.97	7.88	9.20	8.62	2.62	4.10	2.84	3.12
September 3	8.09	3.99	8.81	6.83	2.72	8.02	3.36	2.56
Plat 5, corn:								
August 6	3.67	2.71	5.65	4.71	3.28	2.49	2.95	1.47
August 16	3.26	2.88	1.37	3.29	1.12	1.46	1.07	.90
September 6	1.71	1.40	1.21	.57	1.93	1.48	1.54	1.24

Referring to this table, it will be seen that for some reason the amount of nitrates in the soil under irrigation is less than that in the soil not irrigated, the average for the 4 feet on all the dates for the three plats standing as below:

Nitrates in irrigated and not irrigated ground.

[Parts per million of dry soil.]

Plats.	Irrigated.	Not irrigated.
1, potatoes	5.405	7.452
3 and 4, potatoes	4.593	7.150
5, corn	1.953	2.905
Average	3.984	5.836

From these results it appears that there are notably less nitrates in the irrigated soil. This may be due partly to the fact that larger crops were taken from that ground, but if there was any leaching due to irrigation, this would diminish the nitrates and tend to make them less than in the soil not irrigated.

It might be expected that with a larger water content maintained in the irrigated ground the development of nitrates would be more rapid and thus reduce the difference which has been observed; and this being possible, it appears quite likely that the difference may be due to leaching. The yields which have been secured, however, prove beyond question that the loss of plant food by leaching has not been great enough to overcome the advantage of a better water supply this year. A series of years without manuring might show a different relation, but all lands should be manured more or less, so there is no reason to think that irrigation is likely to prove harmful in the long run if rightly managed.

NITRATES IN THE DRAINAGE WATER FROM THE FIELD.

At the foot of the plats under irrigation, where the pumping plant is situated, there is a spring supplied by water coming from under the field irrigated. The water from this spring and that from the Plover River was examined for nitrates from time to time, and the results found are here given:

Nitrates in drainage water.

[Parts per million.]

Date.	Spring at pump house.	Plover River.	Date.	Spring at pump house.	Plover River.
May 4	33.88	8.80	August 14	58.96	2.42
July 2	78.10	4.49	August 23	51.92	1.85
July 22	67.76	1.85	August 31	70.40	1.74
August 1	49.28	1.50	September 7	70.40	1.72
August 8	59.84	2.07	September 14	77.00	1.65

It will be seen that the drainage from this region has a very high nitrate content; indeed, it is more than three times as high as the average in the local wells at Madison as reported in Bulletin 85 of the

Wisconsin Experiment Station, page 34, and yet the nitrates in the soil of the surface 4 feet at Stevens Point are very much less than in the soils at Madison, as will be seen from a comparison of results found under like conditions at the two places.

Differences in the amounts of nitrates in sandy soil under potatoes at Stevens Point and in clay loams at Madison, Wis.

[Parts per million of dry soil.]

Station.	Date.	First foot.	Second foot.	Third foot.	Fourth foot.
Madison, Wis	August 1, 1901	410.00	48.96	17.55	8.70
Stevens Point	August 2, 1901	6.76	7.43	9.41	2.59
Difference		403.24	41.53	8.14	6.11

From these figures it is clear that there is a very great difference between the two localities, the soils being richer and the drainage waters poorer in nitrates at Madison, but the soils poorer in nitrates and the drainage waters richer at Stevens Point, where the possibilities of leaching are so much greater.

The relatively small amount of nitrates found in the water of the Plover River is probably due to denitrification in the river water after seepage from the adjacent fields has taken place.

LATERAL MOVEMENTS OF NITRATES FROM BENEATH IRRIGATION FURROWS.

Where fields are irrigated by the furrow method there is much less loss of nitrates due to leaching than might at first be anticipated, on account of the tendency of the water and soluble salts already in the ground before irrigation to move laterally by capillarity under the adjacent areas not watered.

In the experiments already cited regarding the soil moisture the nitrates contained in these soil samples were also determined, and this study revealed the fact that immediately after each furrow irrigation the nitrates under the row were increased to a notable extent, as illustrated in the table below:

Lateral movement of nitrates and concentration under areas when furrow irrigation is practiced—Series I.

[Parts per million of dry soil.]

Time of taking sample.	Under row.				Under furrow.			
	First foot.	Second foot.	Third foot.	Fourth foot.	First foot.	Second foot.	Third foot.	Fourth foot.
Upper end of plat 3:								
Before irrigation	9.37	7.17	3.55	2.40	12.12	6.84	4.23	3.81
1 hour after irrigation	12.67	21.55	7.78	27.58	5.57	8.51	12.52	11.54
18 hours after irrigation	11.50	5.51	12.21	23.07	8.15	6.50	6.31	9.25
42 hours after irrigation	6.42	12.18	4.26	3.36	2.17	1.16	1.96	2.22
66 hours after irrigation	12.50	12.34	9.33	5.53	4.10	2.31	5.08	3.74
Center of plat 3:								
Before irrigation	9.01	7.63	6.96	3.30	11.76	9.27	5.14	5.46
1 hour after irrigation	11.23	18.81	11.49	6.77	13.71	3.83	13.25	6.49
18 hours after irrigation	8.90	24.68	11.86	9.27	8.21	6.51	9.64	9.64
42 hours after irrigation	10.49	11.06	6.08	6.43	3.13	5.70	4.95	5.90
66 hours after irrigation	[a]9.84	12.34	7.37	4.96	2.72	3.89	3.94	4.83

[a] Rainfall of 0.34 inch just before these samples were taken.

A similar experiment was made on plat 1, which gave the following results:

Lateral movement of nitrates and their concentration under rows when furrow irrigation is practiced—Series II.

[Parts per million of dry soil.]

Time of taking sample.	Under row. First foot.	Under row. Second foot.	Under row. Third foot.	Under row. Fourth foot.	Under furrow. First foot.	Under furrow. Second foot.	Under furrow. Third foot.	Under furrow. Fourth foot.
Upper end of plat 1:								
Before irrigation	3.63	4.79	3.99	2.52	2.48	1.27	1.15	1.55
1 hour after irrigation	6.81	6.38	3.26	5.97	3.30	1.16	1.42	1.91
24 hours after irrigation	8.33	3.09	3.94	2.33	2.21	1.77	1.98	2.27
48 hours after irrigation	9.85	10.16	8.26	5.21	2.95	2.37	2.85	2.07
Lower end of plat 1:								
Before irrigation	10.56	11.09	4.37	3.69	2.51	1.57	1.38	1.90
1 hour after irrigation	13.78	13.40	9.97	7.00	2.45	2.03	3.84	2.74
24 hours after irrigation	13.19	12.77	4.99	2.78	3.84	4.96	5.36	5.03
48 hours after irrigation	[a]23.31	35.28	11.68	7.19	3.84	3.21	3.25	3.84

[a] Rainfall 0.679 inch just before these samples were taken.

After finding these results at Stevens Point a similar experiment was made on plat 2 at Madison, where the soil is a clay loam, with results of a similar character, as shown by the data of the table following:

Lateral movement of nitrates and their concentration under areas where furrow irrigation is practiced—Series III.

[Parts per million of dry soil.]

Time of taking sample.	Under row. First foot.	Under row. Second foot.	Under row. Third foot.	Under row. Fourth foot.	Under furrow. First foot.	Under furrow. Second foot.	Under furrow. Third foot.	Under furrow. Fourth foot.
Upper end of plat 2:								
Before irrigation	248.26	21.75	6.29	5.80	51.09	34.45	26.60	9.73
4 hours after irrigation	294.80	41.71	11.53	23.04	29.68	35.33	18.90	8.52
26 hours after irrigation	303.92	14.90	10.03	4.77	31.02	40.80	26.80	7.93
50 hours after irrigation	349.26	114.84	10.74	5.42	33.42	32.64	21.06	7.20

From each of these three tables it is clear that there has been a notable increase of nitrates under the rows, and either a loss or else a smaller gain under the furrows.

If the two sections of the tables of Series I and Series II are combined and averaged, and the changes in the nitrate content which was observed after the first interval and after the last intervals are found and expressed in pounds per acre for each foot of depth, they will stand as in the table following:

Observed changes in the amount of nitrates in sandy soil and in clay loam under the irrigation furrows and under the rows between them at different intervals after the ground had been watered.

[Amounts are in pounds per acre expressed as equal parts of calcium and magnesium nitrates.]

Series I. Sandy soil; water by irrigation 4.59 inches, rainfall 0.34 inch.				Series II. Sandy soil; water by irrigation 1.94 inches, rainfall 0.679 inch.				Series III. Sandy soil; water by irrigation 1.85 inches.			
1 hour after irrigation.		66 hours after irrigation.		1 hour after irrigation.		48 hours after irrigation.		4 hours after irrigation.		50 hours after irrigation.	
Under row.	Under furrow.	Under row.	Under furrow.	Under row.	Under furrow.	Under row.	Under furrow.	Under row.	Under furrow.	Under row.	Under furrow.
16.38	−10.02	8.23	−19.73	1.89	−0.52	41.29	−0.39	127.50	− 58.66	276.70	− 84.42
57.89	− 8.56	45.03	−22.47	6.12	.82	66.96	6.21	80.51	− 3.55	375.50	− 7.30
20.42	38.22	14.41	− .84	11.38	6.34	26.99	4.34	23.88	− 35.08	20.23	− 25.24
42.70	21.17	9.19	− 1.69	15.86	3.05	14.45	4.69	79.94	− 5.61	− 1.76	− 11.83
137.39	40.81	76.86	-44.73	34.75	9.69	149.69	15.63	311.83	−102.90	670.67	−128.79

From this table it appears that at the end of the first hour after stopping the irrigation there had been a mean gain per acre of nitrates under the row in Series I of 137 pounds; of 34 pounds in Series II, and at the end of four hours in Series III, one of 311 pounds; at the close of the experiment, Series I showed a gain under the row of over 76 pounds, Series II, one of over 149 pounds, and Series III, a gain of over 670 pounds per acre in the surface 4 feet of soil. These gains of nitrates under the row are due to a shoving forward by capillary sweeping and by percolation of the nitrate-bearing films of water which were investing the soil grains prior to the irrigation or the rainfall, which has been the cause of the concentration observed under the rows.

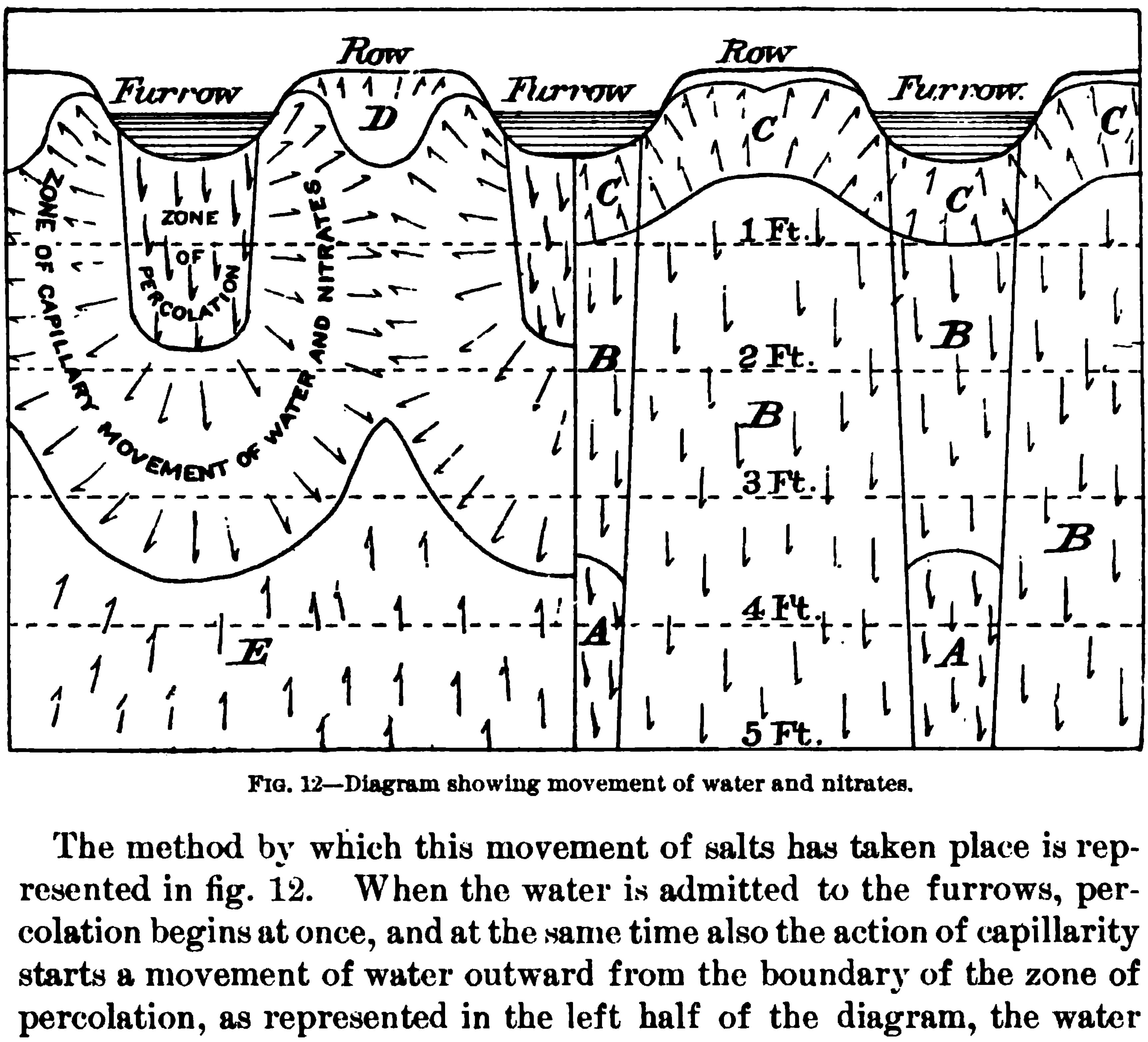

FIG. 12—Diagram showing movement of water and nitrates.

The method by which this movement of salts has taken place is represented in fig. 12. When the water is admitted to the furrows, percolation begins at once, and at the same time also the action of capillarity starts a movement of water outward from the boundary of the zone of percolation, as represented in the left half of the diagram, the water already in the soil being swept forward and with it a large part of the nitrates and other salts dissolved in the water. It is clear that with this action maintained sufficiently long there must be a concentration of nitrates beneath the rows where capillary movement from adjacent furrows meet along a zone beneath D.

In the earlier stages of this process there will be a zone of soil, as at E, where the soil moisture had been in capillary equilibrium or it was moving slowly toward the surface as evaporation took place or the water was removed by the roots of the crop growing on the ground at the time.

It is clear from this diagram that the irrigation should stop as soon as water enough has been applied to leave the ground to a depth of 2 to 3 feet with all the water it can retain capillarily, for if this is not done then there comes to be established the set of conditions illustrated in the right half of the diagram, where more water has been moved by capillarity under the rows from the zone of percolation than the soil is able to retain after the zone of percolation A has receded into the fifth, or lower foot, and the result is there comes to be set up a slower but nevertheless quite rapid percolation downward of the less free water which must carry with it much of the nitrates and other plant food which were at first concentrated under the row where it could best be appropriated by the plants. This last stage had been well established in plat 3 when the 4.59 inches had been added and there was lost a large part of the nitrates which at first were concentrated under the rows, as is proven by the data of Series I. It is even true that the stage had nearly been reached in plat 1 when the water applied was only 1.94 inches, so that when the rain of 0.679 inch fell it was passed and plant food was lost by percolation, even with so small an irrigation.

THE LATERAL EXTENT OF THE INFLUENCE OF IRRIGATION.

The arrangement of the field studies by narrow plats has made it possible to note to what extent laterally the influence of irrigation is felt by the crops growing upon the ground, and the crops of corn and potatoes have been harvested by rows and the individual yields determined to obtain a measure of this influence.

At Madison the subplats were 6 rows wide, with a row watered on one side between each. At Stevens Point the subplats were 4 rows wide, with a row on each side watered on one side. At Madison the rows were 30 inches apart, and at Stevens Point they were 36 inches apart. The results are stated in the tables.

Lateral extent of the influence of irrigation on the total yield of potatoes in a clay loam at Madison, Wis., in 1901, and on sand at Stevens Point, Wis.

ON CLAY AT MADISON.

Plats.	Irrigated both sides.			Irrigated one side.	Not irrigated.		
	2 center rows.	2 rows next to center.	2 rows next to one-half irrigated.	Half irrigated.	2 rows next to one-half irrigated.	2 rows next to center.	2 center rows.
	Bushels per acre.	*Bushels per acre.*	*Bushels per acre.*	*Bushels per acre.*	*Bushels per acre.*	*Bushels per acre.*	*Bushels per acre.*
Plat 2	432.5	429.2	391.0	308.4	209.3	208.0	215.9
Plat 7	353.4	348.9	340.0	288.7	206.1	201.9	201.5
Plat 10	412.0	388.4	356.0	336.9	259.2	241.3	244.7
Average	399.3	388.8	362.3	311.3	224.9	217.1	220.7
Difference	....	−10.5	−26.5	−51.0	−86.4	−7.8	−3.6

Lateral extent of the influence of irrigation on the total yield of potatoes, etc.—Continued.

ON SAND AT STEVENS POINT.

Plats.	Irrigated both sides.			Irrigated one side.	Not irrigated.		
	2 center rows.	2 rows next to center.	2 rows next to one-half irrigated.	Half irrigated.	2 rows next to one-half irrigated.	2 rows next to center.	2 center rows.
	Bushels per acre.	*Bushels per acre.*	*Bushels per acre.*	*Bushels per acre.*	*Bushels per acre.*	*Bushels per acre.*	*Bushels per acre.*
Plat 1	142.4	....	135.3	117.3	90.2	....	86.0
Plats 3 and 4	141.8	....	139.8	130.6	89.7	....	86.7
Average	142.1	....	137.6	124.0	90.0	....	86.4
Difference	....	....	−4.5	−13.6	−34.0	....	−3.6

It is clear from this table that the water applied for irrigation has had the maximum effect at the center of each of the irrigated subplats on each of the five plats, and also that there is a decrease in yield from the center of the irrigated area to the center of that not irrigated. There is the strongest falling off in yield in passing from the rows irrigated on one side to those next to them not irrigated, while the next most abrupt change is the fall to the half irrigation.

The conclusion appears to be warranted that the decrease in yield toward the margins of the fully irrigated subplats is due to a lateral capillary movement of moisture and soluble plant food from the irrigated subplats even to the center of the subplats not irrigated. It is clear, therefore, that the advantages due to the irrigation of both of these types of soil is underestimated rather than overestimated.

It appears to follow from the data that the decrease in yield from the center of the irrigated areas is due rather to the lateral movement of soluble salts carried by the water than to the water itself. Our reasons for this conclusion are, first, the greater effect shown on the heavier and richer soil, requiring less movement of water to carry a given amount of plant food; second, the larger yield at the center of the plats not irrigated, where the wave of salts coming from both ways would be concentrated.

The data for the corn need not be presented here, as its testimony is of the same general import on both soils as that given above.

A SUGGESTION AS TO THE IRRIGATION OF ORCHARDS.

The observations last cited and all of those relating to the capillary sweeping forward of soluble salts in the soil appear to have a practical bearing on the irrigation of orchards where the rows are so far apart that the maximum amount of root surface is not at the center between the rows. The practical bearing of the subject has two phases, first,

where the soil or irrigation water is too highly charged with soluble salts; and, second, where the soil or the irrigation water contains too little soluble salts or only those which are advantageous or harmless.

It is clear that in the first case if the water can be applied first in furrows close to the rows of trees on opposite sides and then in adjacent furrows in succession there will be a tendency to drive alkalis outward from the roots of the trees into the space least occupied by them, and then if drainage must be applied the line of tile should occupy the center of the space between the rows of trees.

On the other hand, if the water and the soil contain only desirable materials the beginning of irrigation at the center of the space between the rows and closing with furrows next to the trees would sweep the plant food to the place where it is most needed.

RECLAIMING ALKALI LANDS BY DRAINAGE.

It is possible also that the principle should be applied in the reclamation of alkali lands by drainage, as offering a method of removing the largest amount of salts with the least amount of water. In this case the practice should be to begin the irrigation midway between the drains and then to advance toward the drains, sweeping the salts above and then finally downward into them, thus taking advantage of the more thorough washing forward of salts which capillary sweeping is able to accomplish.

CONCLUSIONS.

The studies in irrigation at Madison and at Stevens Point, Wis., and the investigations regarding the best amount of soil moisture for crop production suggest the following conclusions:

(1) The amount and distribution of rainfall in climates like that of Wisconsin are not such as to permit well-managed soils to produce maximum yields.

(2) No method of tillage now practiced can very much increase the soil moisture above that which falls in the region as rain and snow.

(3) Good soil management may reduce the loss of water by drainage and by surface evaporation from the soil, but if the precipitation is deficient reduced yields are inevitable unless the deficiency of soil moisture is made good by irrigation.

(4) The major part of the moisture lost during the growing season from the soil occurs through the crop by transpiration, and neither tillage nor mulching can reduce this.

(5) Supplemental irrigation on heavy soils in climates like Wisconsin may increase the yield of hay from twofold to threefold; it may increase the yield of ear corn 25 to 35 bushels per acre, and of potatoes 80 to 100 bushels per acre.

(6) On very poor sandy land supplemental irrigation may increase the yield of potatoes 50 to 75 bushels per acre; of corn, 9 to 15 bushels

per acre; of watermelons, 4 to 8 tons per acre; and of muskmelons, 4 to 6 tons per acre.

(7) The mean fuel cost of pumping water for irrigation at Stevens Point to a height of 33 feet was 27.96 cents per acre-inch when gasoline was 11.98 cents per gallon. At Madison the fuel cost with steam from coal at $5 per ton was 22 cents per acre-inch with a lift of 26 feet.

(8) The cost of irrigation per acre for the season was $6.68 per acre at Madison and $6.70 at Stevens Point.

(9) The profits of irrigation at Madison in 1901 on a clay loam were about $20 per acre on hay, $11 per acre on corn, and $73 per acre on potatoes. At Stevens Point on sandy land the profits were about $30 per acre on potatoes, $1 per acre on corn, $58 per acre on watermelons, and $45 per acre on muskmelons.

(10) The mean daily evaporation from a water surface at Stevens Point from July 16 to October 14 was 0.1496 inch, and it was two and a half times as rapid in July as it was in October.

(11) On the irrigated ground at Stevens Point the mean amount of water in the surface 4 feet of the sandy soil was 4.5 per cent of the dry weight and on the not irrigated ground 3.7 per cent. This small difference in water content is largely responsible for the differences in yield observed.

(12) At the wilting stage for corn the Stevens Point soils contain 11.13 pounds of water in the surface 4 feet; the mean amount in the irrigated ground was 19.03 pounds, or 70.98 per cent more, and in the not irrigated ground it was 15.59 pounds, or 40.07 per cent more.

(13) The maximum amount of water the surface 4 feet of soil at Stevens Point will retain without rapid percolation is about 30.63 pounds per square foot of surface, or about twice the amount for the drought condition for corn and about 11.6 pounds more than the mean maintained in the soil by irrigation.

(14) The moisture in these soils should not be allowed to fall below 19.03 pounds in the surface 4 feet per square foot of area, and 11.6 pounds, or 2 inches of water, is as much as should be applied at one time unless the soil has become drier than 19.03 pounds for the surface 4 feet.

(15) Nitrates and probably other soluble salts will be lost from sandy soils by too heavy irrigation.

(16) The nitrates in the surface 4 feet of the irrigated ground averaged 3.984 pounds per million of dry soil, while in the ground not irrigated the average was 5.836 pounds per million.

(17) The nitrates in the drainage water coming from under the irrigated fields was more than double in September what it was in May, and was more than three times that found in the local wells at Madison under a clay soil.

(18) The nitrates in the surface foot of soil under potatoes at Madison was 410 parts per million of the dry soil, while at Stevens Point

there were only 6.76 parts per million; the difference in yield standing in round numbers 350 to 150 bushels per acre.

(19) In furrow irrigation the nitrates, and probably other soluble salts, also are concentrated under the rows by a capillary sweeping of the salts forward, and this makes the loss by leaching less than it would otherwise be.

(20) The strong lateral movement of salt by capillary sweeping suggests that it may be desirable in irrigating orchards on alkali lands to let the water into the furrows close to the trees first and into succeeding furrows later so as to drive the alkalies away from rather than toward the roots.

(21) In reclaiming alkali lands by drainage it may be that advantage may be taken of the strong capillary sweeping by admitting water to furrows midway between the drainage lines first and then into succeeding furrows, thus driving the salts laterally into the drainage channels or lines of tile.

(22) Farmyard manure alone on the sandy land increased the yields somewhat; water alone did much more, but manure and irrigation together had much the largest effect on the yield.

ACKNOWLEDGMENTS.

I desire to acknowledge the assistance rendered by J. O. Belz, who had charge of the details of the field work in making soil moisture determinations, and by M. W. King, who had charge of the nitrate determinations.

NEW JERSEY.

IRRIGATION IN NEW JERSEY.

By E. B. Voorhees,

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RECORD OF EVAPORATION AND RAINFALL.

In connection with the irrigation work in this State, arrangements were made for studying the amount of water lost by evaporation. The method adopted was that recommended by the Office of Experiment Stations, though a description may not be out of place. The tank is round, consists of heavy galvanized iron, and measures 3 feet in diameter and is 3 feet deep. This was put in the ground 2 feet, and the ground graded up to within 1½ inches of the top. The tank is filled with water up to within 2 inches of the top, and the gain or loss of water is determined by measuring the distance down to the water surface. Two of these evaporation tanks were installed—one at New Brunswick, the other at Vineland. The records in the table given below are for the year beginning July 1, 1900, and ending, approximately, July 1, 1901. In both cases the tanks were emptied at the beginning of cold weather, as it was feared that the freezing would cause an uneven pressure on the tank, thus throwing it out of level, and perhaps causing leakage. Besides, it was impossible to make any readings after the water was frozen. The readings are therefore for the growing season, and the rainfall is recorded for the same period.

Rainfall and evaporation, July, 1900, to July, 1901.

Dates of reading.	Rainfall.	Loss of water by evaporation.
New Brunswick, N. J.:	*Inches.*	*Inches.*
July 1, filled		
July 14	4.04	4.065
July 28	2.50	3.300
August 11	.81	3.435
August 25	1.61	2.810
September 8	.28	2.655
September 22	2.80	2.875
October 6	.44	1.065
October 20	3.22	2.270
October 31	.31	.290
March 15, filled		
March 30	2.02	1.670
April 13	2.51	1.910
April 27	1.09	.940
May 11	2.14	2.140
May 25	1.54	.540
June 8	2.06	1.935
June 22	.06	2.485
July 6	1.62	3.220
	29.05	37.605
		29.050
Evaporation exceeds rainfall		8.555

Dates of reading.	Rainfall.	Loss of water by evaporation.
Vineland, N. J.:	*Inches.*	*Inches.*
July 24	1.59	5.090
August 8	1.70	2.700
August 24	.93	2.430
September 7	1.42	2.170
September 24	1.23	2.230
October 14	5.41	1.410
April 16, filled		
May 9	1.57	3.570
July 9	7.08	9.330
	20.93	28.930
		20.930
Evaporation exceeds rainfall		8.000

While the records at the New Brunswick station were more complete than at Vineland, the losses by evaporation are not very different in the two localities. The important point shown is that more than 8 inches of water in excess of rainfall was evaporated from the surface of the tank during the growing season, although through the period during which the records were kept the rainfall was considerably above the average.

IRRIGATION STUDIES.

In previous experiments[a] it was clearly shown that irrigation by small pumping plants was practicable, and in many cases profitable in New Jersey, particularly for small fruits and certain market-garden crops. It was also pointed out that the need for irrigation came not from any general insufficiency of rainfall, but from the occurrence of short periods of drought, more or less frequent, during the growing season. When such drought comes at a critical period in the growth of a crop, largely increased yields will be obtained as a result of irrigation. Hence, the need and consequent benefits of irrigation are not likely to be uniform from year to year, either in respect to yield or kind of crop. With the fact practically established, that irrigation in the East will be likely to result in increased yields for one or more crops at least twice in three years, the experiments conducted this year were directed more particularly to a study of methods of applying water and of the amounts required. Hence a number of experiments were planned to study (1) the relative effects of different amounts of water, and (2) the relative effects of different methods of applying water.

IRRIGATION EXPERIMENTS WITH SWEET POTATOES AT VINELAND, N. J.

EXPERIMENT NO. 1—FURROW IRRIGATION.

The soil used in this experiment was light and sandy, and, though poor, fairly well adapted for the crop. In the experiment four plats of one-tenth acre each were laid out in the midst of a 3-acre field, on land from which a heavy crop of crimson clover was removed in May.

The plats consisted of two rows, 41 rods long, the land sloping in this distance about 7 feet. The ground was plowed and well prepared and fertilized, and the plants set out June 4. The crop was cultivated after every rain and after every irrigation, if rains were not frequent enough to prevent. One plat was unirrigated, and on the remainder the water was applied in different amounts. The water was added at the upper end of the row, and in the middle or halfway down. Measurements of the quantity used were made by allowing the water to flow out through a hose in a stream of practically constant volume and timing the flow on each plat.

[a] U. S. Dept. Agr., Office of Experiment Stations Bul. 87.

The times of applying water, the amounts used, and the yields are given in the following table:

Sweet potatoes—furrow irrigation.

Time of application of water.	Depth of water applied.	Yield. Prime.	Yield. Seconds.	Yield. Small.	Number of hills dug.	Yield per acre primes and seconds, 150 pounds per barrel.	Yield per acre primes and seconds, full stand.	Actual money returns per acre, $1.50 and $1 per barrel.
	Inches.	*Pounds.*	*Pounds.*	*Pounds.*		*Barrels.*	*Barrels.*	
Plat 1:								
June 29	1.50							
July 19	1.50							
August 14-15	1.25							
September 6	1.50							
Total	5.75	529	194	214	607	48⅕	67¼	$65.83
Plat 2:								
Unirrigated		519	189	175	613	47⅕	65¼	64.50
Plat 3:								
June 29	1.50							
July 19	1.00							
August 14	1.25							
September 6	1.50							
Total	5.25	677	196	207	643	58⅕	77	80.77
Plat 4:								
June 29	1.50							
July 19	.50							
August 11	.75							
August 15	.50							
September 6	1.50							
Total	4.75	550	211	198	618	50¾	69¼	69.09

The unirrigated plat was between two irrigated plats, though properly separated, in order that conditions of soil might be uniform for all plats. On plat 1 four applications of water were made, a total of 5.75 inches. On plat 3, 5.25 inches were added, varying only in the fact that in the second application 1 inch instead of 1½ inches was added. On plat 4, 4.75 inches were added, or an inch less than upon plat 1, applied practically on the same dates. It will be observed that there was a gain in yield and in money value on all of the irrigated plats, though, with the exception of plat 3, the increase was not considerable. This was due, probably, to the shortness of the season, which prevented a full development of all of the potatoes, as usually there is not so large a proportion of "seconds" and small potatoes.

EXPERIMENT NO. 2—IRRIGATION BY SPRINKLING.

Three plats, one-fortieth of an acre each, were included in this experiment. The plants were set out May 19 on land that had no previous crop during the year, and was therefore in better condition than where the furrow irrigation was practiced. The object of this experiment was to learn the effect of what is regarded as large quantities of water in two applications, the same quantities in three applications, and of smaller quantities in four applications. The water was measured by setting tin cans on the ground and catching the sprinkled water.

Sweet potatoes—Irrigation by sprinkling.

Time of application of water.	Amount of water applied.	Yield. Prime.	Yield. Seconds.	Yield. Small.	Number of hills dug.	Yield per acre primes and seconds (150 pounds per barrel).	Yield per acre primes and seconds (full stand).	Actual money returns per acre ($1.50 and $1 per barrel).
	Inches.	*Pounds.*	*Pounds.*	*Pounds.*		*Barrels.*	*Barrels.*	
Plat 1:								
June 28	1.50							
August 14	1.50							
Total	3.00	309	46	25	199	94⅔	114	$135.87
Plat 2:								
June 28	1.00							
August 14	1.00							
September 10	1.00							
Total	3.00	269	57	46	204	87	101⅓	122.80
Plat 3:								
June 28	.50							
August 11	.50							
August 14	.50							
September 6	.50							
Total	2.00	259	47	46	146	81⅗	132⅔	116.13

In plats 1 and 2 the same amount of water was applied, though on No. 2 the amount was made in three applications, 1 inch each; on plat 3 the total amount of water was reduced, applying only one-half inch at each irrigation. No unirrigated plat was included in this experiment, though the advantages of the added water was very evident. The yields were much larger than in the case of the furrow irrigation, due, perhaps, both to the fact that the plants were set earlier, giving more time for maturity, and to the advantage obtained from the method of distributing the water. This experiment shows the decided advantage of the infrequent applications of large quantities of water, as plat 1 shows a much larger proportion of "firsts" than the others, and consequently a larger total value of crop. The value per acre of the potatoes was obtained by using the prevailing prices, viz, $1.50 per barrel for "firsts" and $1 for "seconds," showing an increased value of crop for plat 1 of $19.74 and for plat 2 $6.67 over plat 3, on which the smaller and more frequent applications were made.

AN EXPERIMENT WITH ONIONS.

A still further comparison of methods of irrigation was made in an experiment with onions. The object of the experiment was to determine the relative usefulness of different amounts of water, as well as of furrow irrigation and irrigation by sprinkling. These irrigated plats of one-fortieth acre each were included in each experiment. The onion seed of the Yellow Globe Danvers variety was planted March 10, 11, and 12. The land was in a good state of fertility, and well prepared before seeding. The crop was wheel-hoed nine times, and

all operations were such as to keep the land in good condition and free from weeds. Water was measured as in the case of the sweet potatoes. In the following table are given the complete data of these experiments:

Onions.

Furrow irrigation.				Irrigation by sprinkling.			
Time of application of water.	Amount of water applied.	Yield.	Money returns per acre, approximate.	Time of application of water.	Amount of water required.	Yield.	Money returns per acre, approximate.
	Inches.	*Pounds.*			*Inches.*	*Pounds.*	
Plat 1		57	$27.25	Plat 1:			
Plat 2:				June 29	1.50	60	$43.25
June 29	1.50	85	40.75	July 17	1.50		
July 17	1.50			Plat 2:			
Plat 3:				June 29	1.00	68	32.75
June 29	1.00	115	55.25	July 17	1.00		
July 17	1.00			Plat 3:			
Plat 4:				June 29	.50	72	34.50
June 29	.50	77	37.00	July 17	.50		
July 17	.50						

The value of the different crops was calculated from the actual prices received for the crop. It will be observed, in the first place, that in both cases there was a decided gain from irrigation on all of the plats in the furrow irrigation, averaging $17.08 per acre, or 63 per cent, and in the sprinkled plats a gain of $9.58, or over 35 per cent. In the furrow irrigation the application of 2 inches on plat 3 proved more serviceable than the larger quantities on plat 1 or the smaller on plat 4, whereas on the sprinkled plats the larger application of water on plat 1 was more serviceable than the smaller applications on plats 2 and 3, which accords with the results secured in the sweet-potato experiment. The practicability of sprinkling as a means of irrigation was demonstrated very nicely by William Ash & Sons, whose plat is described in Bulletin No. 87,[a] who irrigated during the year one-third of an acre of cauliflower, followed by lettuce, the gross returns from the two crops being $480. The cost of sprinkling over that of flowing in furrows is so much as to probably render this method inexpedient, except on small areas and for crops of high market value.

EXPERIMENTS IN IRRIGATING ASPARAGUS AND SMALL FRUITS IN 1900 AND 1901.

This work is a continuation of that of which the detailed plan has already been reported.[a] The results here recorded were obtained from plants set in the spring of 1896, and included asparagus, blackberries, raspberries, gooseberries, and currants. All the crops have been irrigated two or three times each year. The accompanying meteoro-

[a] U. S. Dept. Agr., Office of Experiment Stations Bul. 87.

logical table shows the months of the growing season in two years during which the rainfall was light:

Monthly precipitation on the experiment grounds for the years ended October 31, 1900 and 1901.

Month.	1900.	1901.	Month.	1900.	1901.
	Inches.	*Inches.*		*Inches.*	*Inches.*
November	4.23	4.27	June	2.64	0.81
December	2.06	2.37	July	6.94	9.12
January	4.35	2.11	August	2.24	8.90
February	5.46	.76	September	3.30	1.86
March	3.40	5.19	October	3.53	1.89
April	2.38	7.39			
May	5.58	5.01	Total	46.11	49.68

While there was a noticeable shortage of rain in one or two months of the growing season in each year, the length of the period and the time of the deficiency were such as apparently not to exert so marked an effect on the growth and ripening of crops as was the case with the crops the previous year. For example, the shortage in 1900 was not serious until the latter part of June, after the main crop of asparagus was harvested, and again in August and September, practically at the end of the growing season. In 1901, while the shortage was serious in June, it was preceded by an excess in April and May and followed by an excess in July, making it possible for the crops harvested in June to obtain a sufficient supply of moisture, and those harvested in July, while retarded in their growth, were able to largely recuperate on account of the excess in that month. This may have been due in part to the fact also that the yield of berries this year was not large, owing to a poor set. The shortage in September and October did not affect the crops of this year, though it may have its influence on subsequent crops. The effect is, however, not now noticeable. The table following shows the time of irrigation and the amounts of water applied during the two years for the different crops:

Date of application of water and amount applied.

ASPARAGUS.

Year.	Date of application.	Depth.
		Inches.
1900	June 30	0.75
1900	July 18	1.00
1900	Sept. 10	1.00
	Total	2.75
1901	June 17	.75
1901	June 24	.75
	Total	1.50

Date of application of water and amount applied—Continued.

BLACKBERRIES.

Year.	Date of application.	Depth.
		Inches.
1900	July 3	1.00
1900	July 17	1.00
	Total	2.00
1901	June 28	1.00

RASPBERRIES.

1900	July 2	0.75
1900	July 6	1.00
1900	July 16	1.00
	Total	2.75
1901	June 22	1.00
1901	June 29	1.00
	Total	2.00

CURRANTS.

1900	July 19	1.00
1901	June 19	.75
1901	June 25	1.00
1901	July 1	1.00
	Total	2.75

GOOSEBERRIES.

1900	July 19	1.00
1901	June 19	.75
1901	June 25	1.00
1901	July 1	1.00
	Total	2.75

In no case was more than 1 inch of water applied at any one time, for the reasons pointed out in Bulletin No. 87, and as has been the practice in the past the irrigation was begun when the surface soil became dry and before the plants showed sign of suffering. At no time during the season of growth did the irrigated plats show evidence of lack of water; the growth and development of both plant and fruit were normal.

ASPARAGUS.

While the asparagus was set in 1896, but little cutting was done until 1900. The following table of yields of asparagus, calculated in

1900 and 1901, show that different varieties of this vegetable vary widely in reference to their yield, though they are somewhat erratic:

Yields of asparagus per acre on irrigated and unirrigated plats, 1900 and 1901.

Variety.	1900.		1901.	
	Plat 1.	Plat 2.	Plat 1.	Plat 2.
	Pounds.	*Pounds.*	*Pounds.*	*Pounds.*
Barr Mammoth:				
Irrigated	6,420	4,770	6,960	4,370
Unirrigated	5,150	4,910	6,000	5,970
Gain from irrigation	1,270	−140	960	−1,600
Donald Elmira:				
Irrigated	6,020	5,440	7,350	6,510
Unirrigated	6,650	5,470	7,280	5,720
Gain from irrigation	−630	−30	70	790
Columbian Mammoth White:				
Irrigated	5,260	5,260	5,190	5,910
Unirrigated	5,810	4,670	6,130	4,400
Gain from irrigation	−550	590	−940	1,510
Palmetto:				
Irrigated	5,910	6,900	6,620	8,700
Unirrigated	8,620	7,920	9,940	8,060
Gain from irrigation	−2,710	−1,020	−3,320	640
Conover Colossal:				
Irrigated	5,420	5,560	6,840	7,340
Unirrigated	5,740	4,560	7,360	4,980
Gain from irrigation	−320	1,000	−520	2,360
Giant Brunswick:				
Irrigated	2,780	2,960	2,440	3,300
Unirrigated	3,760	3,280	4,070	3,780
Gain from irrigation	−980	−320	−1,630	−480

A study of the yield in 1900 shows but little effect from irrigation. In fact, in but three cases out of the twelve was there a gain from the application of water. The differences in yield, therefore, must be attributed to some other cause than lack of water, unless application of water in previous years may have had some effect in reducing the vigor of the plant. In 1901 there is a very considerable gain from irrigation, six out of the twelve plats showing a gain as against three in 1900, though the total yield from the unirrigated plats was greater than from the irrigated.

In perennial crops of this sort, which root deeply, short periods of drought would naturally be less disastrous than in the case of certain other vegetables. Still, there is much to be learned as to the application of water. It is well known that the rapidity of the growth of the young shoots in early spring is very materially influenced by the temperature, and it may have been that the application of water in summer reduced the temperature of the soil, and this neutralized any beneficial effect that might have been derived from the added water, if at the same time the temperature could have been maintained at a higher point. This point will be taken into consideration in future

studies, as the bed is just in the beginning of its usefulness and will serve for a number of years for demonstration purposes.

Another point which may have affected the results, or at any rate may have been a modifying factor, was the fact that rust was very general in 1899 and 1900, particularly, and the plants were used by the botanist to study the influence of applied fungicides.

BLACKBERRIES.

The following table shows the yield of blackberries in 1900 and 1901 and the effect of irrigation:

Yields of blackberries per acre on irrigated and unirrigated plats, 1900 and 1901.

Variety.	1900.		1901.	
	Plat 1.	Plat 2.	Plat 1.	Plat 2.
Early Harvest:	*Quarts.*	*Quarts.*	*Quarts.*	*Quarts.*
Irrigated	4,335	6,389	2,483	2,041
Unirrigated	5,304	5,967	1,898	1,813
Gain from irrigation	--969	422	585	228
Wilson, Jr:				
Irrigated	7,397	4,218	2,249	903
Unirrigated	5,629	4,556	1,397	1,085
Gain from irrigation	1,768	−338	852	−182
Eric:				
Irrigated	6,389	6,305	1,761	1,755
Unirrigated	6,357	6,695	2,203	1,430
Gain from irrigation	32	−390	−442	325
Agawam:				
Irrigated	3,562	4,264	955	1,690
Unirrigated	3,757	4,725	240	1,209
Gain from irrigation	- 195	-461	715	481
Taylor:				
Irrigated	5,005	5,193	1,586	1,670
Unirrigated	4,875	4,764	234	1,592
Gain from irrigation	130	429	1,352	78
Eldorado:				
Irrigated	5,596	4,186	2,411	2,866
Unirrigated	7,273	5,986	1,358	3,250
Gain from irrigation	1,677	-1,800	1,053	-384

In 1900 the yields of all varieties were good, though a wide difference was observed. In five cases only out of the twelve was there a gain from irrigation which ranged from 32 quarts to 1,768 quarts per acre. Taking the whole number of plats, however, there was no gain from irrigation; that is, the unirrigated plats show a larger total yield than the irrigated. In 1901 nine cases out of the twelve showed an increased yield ranging from 78 to 1,352 quarts per acre, and where the differences were not in favor of irrigation the yields were much smaller as the maximum gain on any unirrigated plat was 442 quarts in the ca e of Erie on plat 1. The total yields per acre were, however, much lower than in 1900, due to a poor set of fruit, and which was true for all varieties and plats. The actual gain from irrigation in

1901 was 4,661 quarts, or an average of 388 quarts per acre, worth at prices received this year, $38.80, a very handsome return from the labor and trouble of irrigation. The larger price per quart was due to the generally low yields throughout the State.

RASPBERRIES.

The yields of raspberries for the years 1900 and 1901 on irrigated and unirrigated plats are as follows:

Yields of raspberries per acre on irrigated and unirrigated plats, 1900 and 1901.

Variety.	1900.		1901.	
	Plat 1.	Plat 2.	Plat 1.	Plat 2.
	Quarts.	*Quarts.*	*Quarts.*	*Quarts.*
Cuthbert:				
Irrigated	3,039	3,128	1,405	2,098
Unirrigated	1,910	4,049	702	2,356
Gain from irrigation	1,129	−921	703	−258
Marlboro:				
Irrigated	1,148	1,336	277	920
Unirrigated	1,019	1,742	475	1,168
Gain from irrigation	129	−406	−198	−248
Turner:				
Irrigated	3,950	4,346	2,326	3,009
Unirrigated	4,385	4,395	1,623	3,870
Gain from irrigation	−435	−49	703	−861

The raspberries also show a low total yield, and but little influence from irrigation. This was true of both 1900 and 1901. In two cases only out of six in each year was there any gain, though in 1901 the yields from irrigated plats were practically identical with those from the unirrigated.

CURRANTS.

The yields of currants for the years 1900 and 1901 on irrigated and unirrigated plats are as follows:

Yields of currants per acre on irrigated and unirrigated plats, 1900 and 1901.

Variety.	1900.		1901.	
	Plat 1.	Plat 2.	Plat 1.	Plat 2.
	Quarts.	*Quarts.*	*Quarts.*	*Quarts.*
Fay Prolific:				
Irrigated	3,042	1,446	5,160	2,964
Unirrigated	1,746	3,768	5,292	6,108
Gain from irrigation	1,296	−2,322	−132	−3,144
Red Dutch:				
Irrigated	6,408	6,672	9,708	9,816
Unirrigated	5,508	5,076	8,784	7,236
Gain from irrigation	900	−1,596	−924	−2,580
Victoria:				
Irrigated	8,136	6,834	9,024	7,896
Unirrigated	6,906	4,776	8,064	6,336
Gain from irrigation	1,230	2,058	960	1,560
White Grape:				
Irrigated	2,088	1,380	7,248	4,512
Unirrigated	1,962	1,014	4,224	3,828
Gain from irrigation	126	366	3,024	684

In the case of currants there is a very decided gain from irrigation in both years. In 1900 seven out of the eight plats showed a very considerable gain from irrigation. Owing to the very wide differences in yield of the different varieties the gains were not uniform. The largest gains from irrigation are shown in the case of Red Dutch and Victoria varieties, the average gain per acre from irrigation being 656 quarts. The prices of currants averaged 8 cents per quart at the field, making a gain per acre of $52.48. In the case of Fay Prolific, on plat 2, there is evidently some trouble with the plants, as in both years the differences are greater than can be accounted for on any other basis, much larger yields being obtained from the unirrigated plat, and in both cases the difference was greater than the total yield on the irrigated plat. In 1901 in six out of the eight cases there was a very decided gain from irrigation, ranging from 684 to 3,024 quarts, an average of 807 quarts, or $64.56 per acre, somewhat greater than in 1900.

In the case of the currants and gooseberries an additional benefit of irrigation comes from the cooling of the soil. This advantage is very marked if very hot weather occurs just previous to the period of ripening.

GOOSEBERRIES.

The yields of gooseberries for the years 1900 and 1901 on irrigated and unirrigated plats are as follows:

Yields of gooseberries per acre on irrigated and unirrigated plats, 1900 and 1901.

Variety.	1900.		1901.	
	Plat 1.	Plat 2.	Plat 1.	Plat 2.
Downing:	*Quarts.*	*Quarts.*	*Quarts.*	*Quarts.*
Irrigated	16,104	12,180	1,680	1,620
Unirrigated	16,356	10,152	2,724	1,524
Gain from irrigation	−252	2,028	−1,044	96
Columbus:				
Irrigated	7,200	4,176	2,442	1,920
Unirrigated	7,344	3,096	2,736	1,728
Gain from irrigation	−144	1,080	−294	192
Houghton:				
Irrigated	16,116	14,796	6,096	6,312
Unirrigated	14,880	11,496	4,512	4,032
Gain from irrigation	1,236	3,300	1,584	2,280
Triumph:				
Irrigated	6,228	3,654	2,232	1,590
Unirrigated	6,168	3,012	3,336	2,550
Gain from irrigation	60	642	−1,104	−960

In the case of gooseberries in 1890 there is a gain from irrigation in six out of the eight plats, ranging from 60 quarts to 3,300 quarts. The yield, particularly on the Downing and Houghton, was extraordinary, thus making the average increased gain per acre from irrigation 994 quarts per acre, which, at the prevailing price in the field (6 cents per quart) made a gain from irrigation worth $59.64. In 1901 there was a gain in only half the cases, though on the whole the yield on the irrigated plats was 94 quarts per acre greater than on the unirrigated. The very hot weather in June had the effect of injuring very materially the yield of both the irrigated and the unirrigated, causing many to sunburn and drop.

SECOND PROGRESS REPORT ON SILT MEASUREMENTS.

By J. C. Nagle,

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LOCATION.

Since the first progress report on silt measurements[a] was made, daily measurements of gauge heights and periodic collection of samples of river water have been continued on the Brazos River at Jones Bridge, Brazos County, Tex., and at Wichita Falls on the Wichita River. In addition to the collections made at these points a few samples were received, taken from the Rio Grande at El Paso, Tex., during 1900 under direction of the consulting engineer of the International (Water) Boundary Commission. Two additional gauging stations were established in the Texas coast country, one on the Brazos River at Richmond, and another on the Colorado River at Wharton. The recent heavy use of flowing water in rice irrigation in this coastal region made it desirable to obtain information regarding the available discharge during the irrigating season, for, on the Colorado especially, the draft upon the flow made by lands already under cultivation is sufficient grounds for apprehension lest these and the acreage for which plans and projects are already under foot will lead to serious shortage of water during dry seasons. Prospective irrigators in that section have already come to realize this and have made a number of inquiries regarding the discharge which a year ago they thought sufficient to irrigate all the land available for rice along this river.

METHODS.

The method of collecting samples of water at the Jones Bridge and Wichita Falls stations was the same as that described in the 1900 report.

On the Wichita River the old gauge rod set in February, 1900, has done continuous service, but the shifting sediment at the bottom of the river has interfered somewhat with its working toward the latter part of the time over which the records extend. At the Colorado station and both of the Brazos stations graduated chains have done duty in place of gauge rods, the distance to the water surface below a given point on a bridge floor being measured daily at each station.

[a] U. S. Dept. Agr., Office of Experiment Stations Bul. 104.

DISCHARGE AND SILT MEASUREMENTS.

BRAZOS RIVER.

The range of gauge heights for the last sixteen months has been small in comparison with what they were during the time covered by the previous report. At no time during this interval has the river been anywhere near the overflow stage, which occurs at a gauge reading of about 39 feet. The highest stage reached since the first report was made occurred on June 4, 1901, when the gauge stood at 13.6 feet. On May 21 the river was nearly as high, the gauge reading 13.35 feet.

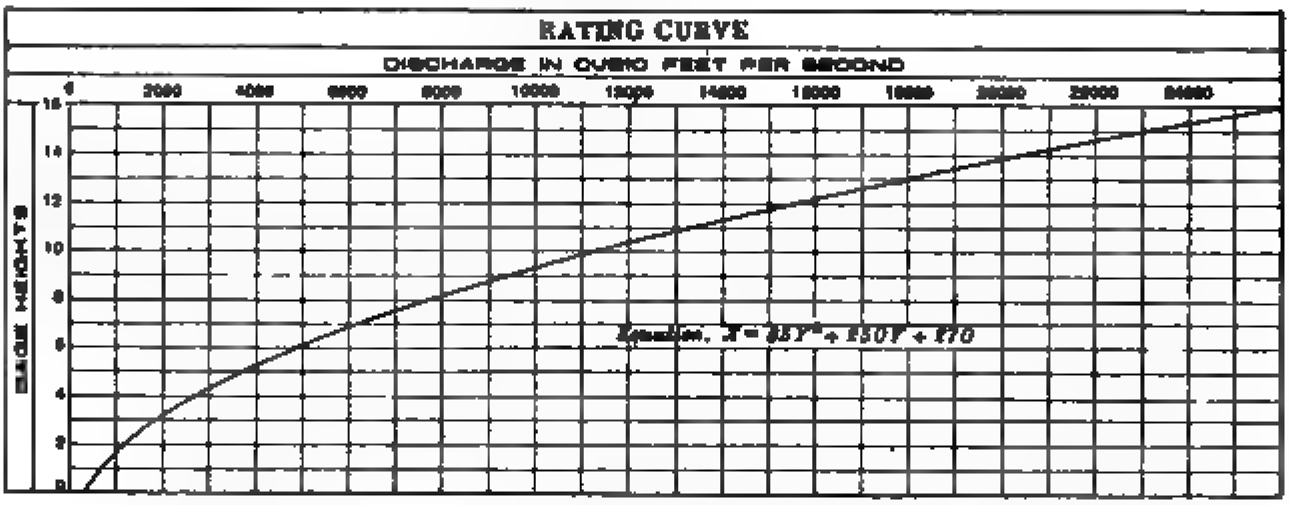
On the dates given in the following table discharge measurements were made with the results shown:

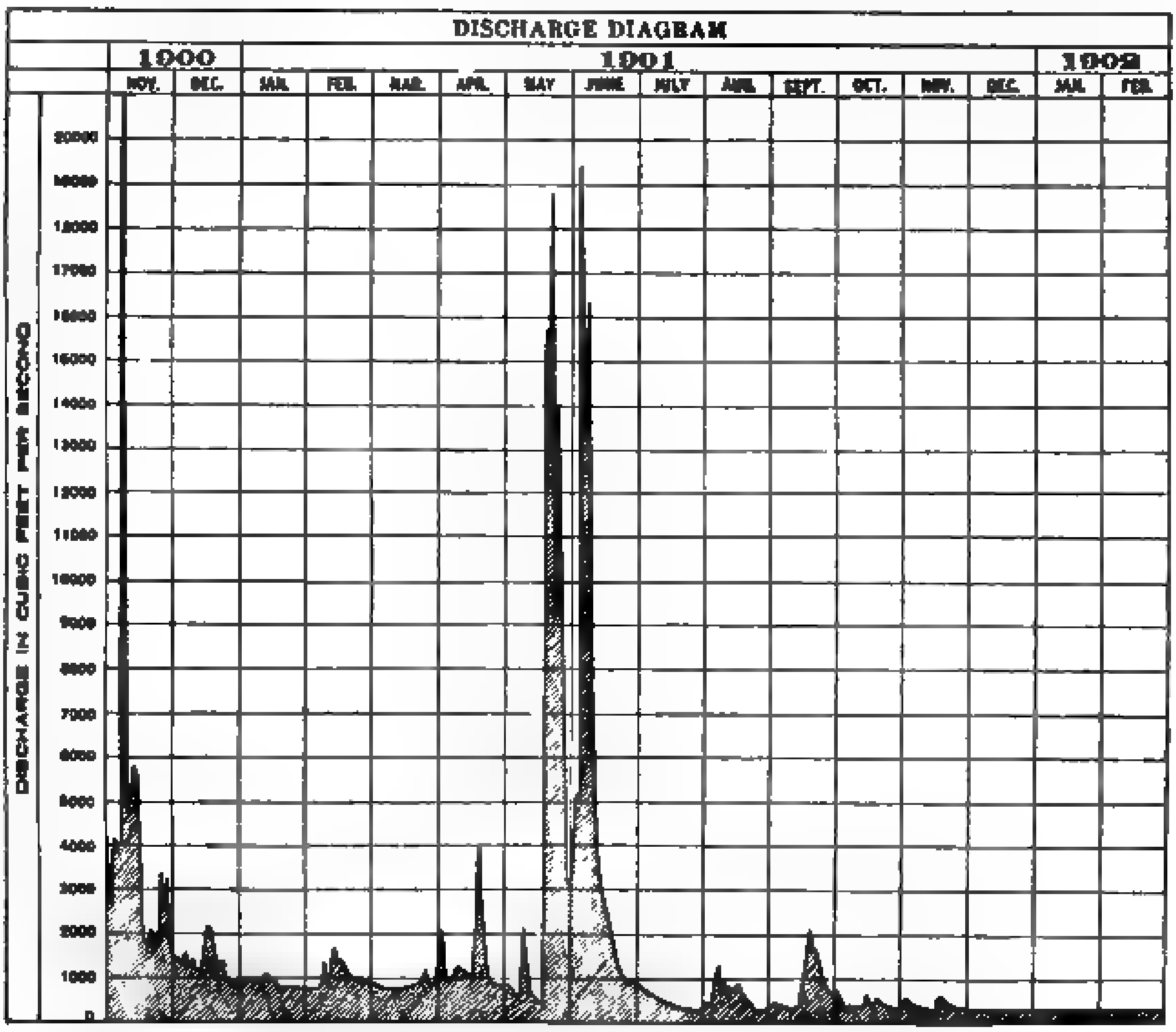
Measured discharges of the Brazos River at Jones Bridge, Brazos County, Tex.

Date.	Gauge height.	Discharge.	Velocities measured by—
	Feet.	*Cu. ft. per sec.*	
November 18, 1900	3.00	1,720	Current meter.
January 6, 1901	1.60	900	Do.
March 3, 1901	1.45	820	Do.
April 21, 1901	2.65	1,530	Do.
May 21, 1901	12.20	15,975	Do.
May 25, 1901	10.90	13,267	Do.
May 27, 1901	8.20	8,140	Floats.
May 29, 1901	5.30	4,075	Do.
May 31, 1901	4.40	3,040	Do.
June 2, 1901	6.50	5,510	Do.
June 7, 1901	12.35	16,372	Current meter.
July 28, 1901	.20	275	Do.
September 3, 1901	.50	414	Do.
November 10, 1901	.55	472	Do.
January 5, 1902	.15	235	Do.

From these measurements a curve was platted and a rating table made. From this table and the record of gauge heights the discharge of the river has been computed. During the time covered by this report the changes in the cross section of the stream at the place of measurement have not been so marked as to necessitate the construction of more than the one rating table, although they have been sufficient to reduce to a slight extent the accuracy of the discharge table given below. Pl. LXI shows the changes in the bottom of the river for the four most pronounced cases. Near the left bank the extreme change in depth amounted to upward of 2½ feet, but on account of a bar farther down the river this change did not make very serious differences in the discharges for a given gauge height. When the water was shallow the velocity was greater than when the channel was deep. It is believed that the discharges as given are as nearly correct as the limits of error in this class of work would lead one to expect.

DIAGRAMS SHOWING CROSS SECTIONS, RATING CURVE, AND DISCHARGE OF BRAZOS RIVER AT JONES BRIDGE.





Discharge of the Brazos River at Jones Bridge, Brazos County, Tex.

Day.	1900. November.	1900. December.	1901. January.	1901. February.	1901. March.	1901. April.	1901. May.	1901. June.	1901. July.	1901. August.	1901. September.	1901. October.	1901. November.	1901. December.	1902. January.	1902. February.
	Acre-feet.	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*
1	4,760	2,965	1,761	1,466	1,609	4,336	1,609	8,600	1,609	670	825	1,285	641	670	488	488
2	4,264	2,698	1,761	1,466	1,609	3,693	1,609	10,481	1,609	894	966	1,079	1,002	670	488	488
3	4,165	2,698	1,761	1,561	1,609	2,569	1,511	9,834	1,511	825	825	894	1,079	641	488	488
4	6,942	2,828	1,761	1,561	1,511	2,087	1,373	38,463	1,373	793	825	793	1,158	641	488	488
5	6,744	2,569	1,761	1,561	1,466	1,974	1,200	29,860	1,200	793	825	730	1,158	641	464	488
6	6,744	2,321	1,761	1,561	1,373	1,761	1,079	26,391	1,079	2,202	793	536	1,079	641	464	488
7	6,744	2,442	1,761	1,561	1,373	2,029	1,974	32,374	1,002	2,144	793	670	1,002	641	464	464
8	73,980	2,321	1,658	2,698	1,373	2,442	3,541	24,148	1,002	2,763	730	670	966	641	464	464
9	22,212	2,442	1,658	2,321	1,373	2,442	4,088	13,738	966	1,285	730	670	894	670	464	464
10	8,925	2,321	1,761	1,866	1,373	2,442	2,965	11,713	966	1,511	730	670	793	670	464	442
11	8,627	2,321	1,974	1,974	1,373	2,442	1,866	9,082	894	1,658	670	670	700	670	464	442
12	10,512	2,202	2,321	3,245	1,373	2,321	1,511	7,450	825	1,609	670	641	700	641	464	442
13	10,115	2,202	2,087	2,698	1,373	2,202	1,378	6,181	825	1,511	670	641	670	641	464	442
14	9,916	3,392	1,974	2,763	1,373	2,087	1,119	5,592	793	1,511	641	613	613	613	464	442
15	7,338	4,336	1,761	2,698	1,373	2,087	1,039	4,767	793	1,511	641	670	561	613	464	442
16	4,958	4,336	1,761	2,698	1,373	2,087	894	4,507	793	1,418	1,866	1,285	561	587	464	442
17	3,867	2,698	1,658	2,442	1,373	2,087	825	3,927	793	1,761	2,965	966	1,242	561	442	442
18	3,411	2,569	1,658	2,321	1,373	5,592	894	3,541	793	1,658	4,252	894	1,200	561	442	442
19	3,392	2,698	1,466	2,202	1,373	8,013	31,220	3,318	793	1,511	3,174	825	1,158	561	442	488
20	4,507	2,698	1,561	2,029	1,466	4,088	25,556	2,965	793	1,373	3,318	966	1,158	587	442	488
21	2,965	2,698	1,561	1,974	1,511	3,245	37,200	2,763	793	1,158	3,174	1,079	1,119	587	442	488
22	2,965	2,698	1,561	1,974	1,511	2,442	18,129	2,442	730	1,002	2,828	1,002	1,079	561	442	464
23	4,679	2,698	1,561	1,866	1,609	2,029	20,835	2,202	730	966	2,442	894	1,039	561	442	464
24	3,104	1,974	1,561	1,761	2,321	1,761	27,669	1,866	730	825	2,202	793	966	561	442	464
25	6,592	1,761	1,561	1,761	2,087	1,658	24,735	1,761	730	730	1,920	730	894	561	464	464
26	5,982	1,761	1,561	1,658	1,866	1,658	19,911	1,658	730	730	1,609	730	825	536	488	442
27	5,034	1,761	1,561	1,658	1,658	1,658	15,937	1,609	670	670	1,511	670	793	536	488	442
28	6,592	1,761	1,561	1,658	1,658	1,658	10,483	1,609	641	670	1,373	670	730	536	488	442
29	3,104	1,761	1,561	....	1,609	1,609	7,230	1,609	641	670	1,285	670	700	512	488	....
30	3,104	1,761	1,561	....	1,609	1,609	6,385	1,609	641	641	1,200	670	670	488	488	....
31	....	1,761	1,466	....	2,321	....	5,689	....	670	641	....	641	....	488	488	....
Total	256,244	77,452	52,701	57,002	48,252	78,108	281,449	276,060	28,118	38,104	46,458	24,717	27,150	18,488	14,448	12,944

The table which follows shows the run-off of the drainage area of the Brazos for the sixteen months covered by this report. The run-off is computed both inclusive and exclusive of that portion of the watershed lying above the 3,000-foot contour, for the reasons set forth in the first report:

Run-off from drainage area of Brazos River at Jones Bridge, Brazos County, Tex.

Month.	Mean discharge.	Discharge for month.	Run-off. For 37,400 square miles. Depth.	Run-off. For 37,400 square miles. Per square mile.	Run-off. For 30,150 square miles. Depth.	Run-off. For 30,150 square miles. Per square mile.
	Cu. ft. per sec.	*Acre-feet.*	*Inch.*	*Cu. ft. per sec.*	*Inch.*	*Cu. ft. per sec.*
1900.						
November	4,306.5	256,244	0.1285	0.1151	0.1594	0.1428
December	1,259.5	77,452	.0388	.0337	.0482	.0418
1901.						
January	857.1	52,701	.0264	.0229	.0328	.0284
February	1,026.3	57,002	.0286	.0274	.0355	.0340
March	784.6	48,252	.0242	.0210	.0300	.0260
April	1,312.6	78,108	.0392	.0351	.0486	.0435
May	4,577.3	281,449	.1411	.1224	.1750	.1518
June	4,639.3	276,060	.1384	.1240	.1717	.1539
July	457.3	28,118	.0141	.0122	.0175	.0152
August	619.8	38,104	.0191	.0166	.0237	.0206
September	780.7	46,453	.0233	.0209	.0289	.0259
October	402.1	24,717	.0124	.0108	.0154	.0133
November	456.3	27,150	.0136	.0122	.0169	.0151
December	300.7	18,488	.0093	.0080	.0115	.0100
1902.						
January	235.0	14,448	.0072	.0063	.0090	.0078
February	233.1	12,944	.0065	.0062	.0081	.0077
Total for 16 months	....	1,337,690	.6707	....	.8322	....

The general results of all the discharge and run-off measurements so far made on Brazos River are brought together below:

Total discharge and run-off, by years, from August 1, 1899, to December 31, 1901.

Period.	Discharge.	Run-off. For 37,400 square miles. Depth.	Run-off. For 37,400 square miles. Per square mile.	Run-off. For 30,150 square miles. Depth.	Run-off. For 30,150 square miles. Per square mile.
	Acre-feet.	*Inches.*	*Cu. ft. per sec.*	*Inches.*	*Cu. ft. per sec.*
August 1 to December 31, 1899	1,165,310	0.5840	0.1027	0.7250	0.1274
January 1 to December 31, 1900	8,706,796	4.3523	.3218	5.4136	.3991
January 1 to December 31, 1901	976,602	.4897	.0361	.6075	.0448

The foregoing shows that the discharge and run-off in 1901 were but little more than a tenth of what they were in 1900. During 1900 the rainfall throughout the area tributary to the Brazos would probably average 20 to 25 per cent in excess of the normal, while in 1901 the deficiency was probably as much as 25 to 30 per cent. In fact, the precipitation during 1901 has been less than for many years and in portions of the State much distress has resulted from the shortage.

Samples of the water for sediment determination have been taken with more frequency than during the period covered by the first progress report, but still there were not a sufficient number taken at the times of high water to furnish as close a degree of approximation to the total silt carried as could have been desired. Ordinarily a sample was taken once a week, but at times of high water the observers were instructed to take samples much oftener. Failure to properly appreciate the importance of this part of the work caused the observers to sometimes neglect to take as many samples as would have been desirable.

With the exception of the sample taken on May 25, all the samples were taken in the tin collecting cans described in the first progress report and in the manner there stated. When the water was clear, or nearly so, but one sample was taken; at other times either three or four samples were taken at varying depths. The water after being well shaken was placed in settling tubes and allowed to stand one week, at the end of which time the volume of sediment was read in the graduated tubes, and the percentage of sediment computed from this. A few samples were allowed to stand a longer time, but so far the number of tubes available has been insufficient to admit of the rate of subsidence being determined with any degree of accuracy for a sufficient length of time to determine the law for each class of samples.

The table given below shows the results found for the samples of water collected from the Brazos River. The time of settling was one week, as stated, but a few samples were allowed to stand one month, and the approximate shrinkage at the end of thirty days, as compared with the volume at the end of one week, shows about the same average result as stated in the first progress report—10 per cent reduction in volume during the interval. A few samples were allowed to stand a somewhat longer time, and these showed still further shrinkage, so that until more accurate results can be obtained it will be assumed, as was done in the former report, that the decrease in volume at the end of one year will be about one-fourth of the volume at the end of one week.

Silt determinations for the Brazos River at Jones Bridge.

When collected.	Silt in water.						Discharge.	Total silt.	Appearance of water.	Time required to settle clear.
	Surface.	One-third depth.	Mid depth.	Two-thirds depth.	Bottom.	Mean.				
1900.	*Per cent.*	*Per ct.*	*Per cent.*	*Per ct.*	*Per ct.*	*Per ct.*	*Cu. ft. per sec.*	*Cu. ft. per sec.*		*Hours.*
November 18.	0.150	0.140		0.150	0.140	0.145	1,720	2.5	Light red	3
1901.										
January 6			0.000			.000	900	.0	Clear	
January 13			.000			.000	1,052	.0	do	
January 21			.000			.000	787	.0	do	
January 27			.000			.000	787	.0	do	
February 3			.000			.000	787	.0	do	
February 10			.133			.133	941	1.3	Cloudy	9
February 16			.000			.000	1,360	.0	Clear	
February 24			Trace.			Trace.	888	.0	Faintly cloudy	
March 3			.000			.000	820	.0	Clear	

Silt determinations for the Brazos River at Jones Bridge—Continued.

When collected.	Silt in water. Surface.	One-third depth.	Mid depth.	Two-thirds depth.	Bottom.	Mean.	Discharge.	Total silt.	Appearance of water.	Time required to settle clear.
							Cu. ft. per sec.	*Cu. ft. per sec.*		
1901—Cont'd.	*Per cent.*	*Per ct.*	*Per cent.*	*Per ct.*	*Per ct.*	*Per ct.*				*Hours.*
March 10			Trace.			Trace.	692	0.0	Clear	
March 17			Trace.			Trace.	692	.0	.....do	
March 24			0.000			0.000	1,170	.0	.....do	
March 27			.123			.123	836	1.0	Cloudy	9
April 1			.204			.204	2,186	4.5	Slightly muddy	9
April 8			.086			.086	1,231	1.1	Nearly clear	9
April 19	0.460				0.549	.505	4,040	20.4	Muddy	12
April 22	.105		Missing.		.094	.100	1,231	1.2	Nearly clear	9
April 28			Trace.			Trace.	836	.0	Faintly cloudy	
May 5			.080			.080	605	.5	Almost clear	
May 9			.398			.398	2,061	8.2	Muddy	7
May 16			Trace.			Trace.	451	.0	Clear	
May 19	2.070	1.950		2.080	Spoiled.	2.033	15,740	320.0	Dark muddy	6
May 21	2.840	2.780		2.770	2.750	2.785	15,975	444.9	Red	4
May 24	1.250	1.290		1.410	1.450	1.350	13,949	188.3	.....do	3½
May 25	1.290	1.280		1.250	1.440	1.315	13,267	174.4	Dark, with red tinge.	5
June 2	1.325		.834		1.105	1.088	5,510	59.9	Muddy	8
June 6	Missing.	3.820		3.467	4.000	3.762	13,305	500.3	Very red	1¼
June 10	2.202		3.088		2.380	2.557	5,906	151.0	.....do	2
June 16			1.810			1.810	2,272	41.1	Red	2¼
June 22	.460				.323	.392	1,231	4.8	.....do	2
July 1			.210			.210	811	1.7	Faint red	2¼
July 7			.000			.000	505	.0	Clear	
July 14			.000			.000	400	.0	.....do	
July 21			.000			.000	400	.0	.....do	
July 28			.000			.000	275	.0	.....do	
August 4			.000			.000	400	.0	.....do	
August 6			.000			.000	1,110	.0	.....do	
August 11			.000			.000	836	.0	.....do	
August 18			.000			.000	836	.0	.....do	
August 25			.000			.000	368	.0	.....do	
September 3			.000			.000	414	.0	.....do	
September 8			.000		.000	.000	368	.0	.....do	
September 15			.000			.000	323	.0	.....do	
September 16			.132			.132	941	1.2	Slightly muddy	7
September 19	.502				.437	.470	1,600	7.5	Muddy	7
September 22			.287			.287	1,426	4.1	Slightly muddy	7
September 29			Trace.			Trace.	648	.0	Clear	
October 5			.000			.000	368	.0	.....do	
October 12			.000			.000	323	.0	.....do	
October 20			.000			.000	487	.0	.....do	
October 27			.000			.000	338	.0	.....do	
November 3			.000			.000	544	.0	.....do	
November 10			.000			.000	472	.0	.....do	
November 17			.000			.000	626	.0	.....do	
November 24			.000			.000	487	.0	.....do	
December 1			.000			.000	338	.0	.....do	
December 8			.000			.000	323	.0	.....do	
December 15			.000			.000	309	.0	.....do	
December 22			.000			.000	283	.0	.....do	
December 28			.000			.000	270	.0	.....do	
1902.										
January 5			.000			.000	235	.0	.....do	
January 12			.000			.000	234	.0	.....do	
January 19			.000			.000	223	.0	.....do	
January 26			.000			.000	246	.0	.....do	
February 2			.000			.000	246	.0	.....do	
February 3			.000			.000	234	.0	.....do	
February 16			.000			.000	223	.0	.....do	
February 23			.000			.000	234	.0	.....do	

Excluding the set of samples taken on November 18, 1900, which was included in the 1900 report, there were only five sets of four samples each taken during the period covered by this report, and of these two sets were defective, one sample of one set having been spoiled by a

dirty bottle and one of the other set being missing. The mean is as follows:

Percentages of silt at different depths.

	Per cent.
From top	1.793
From one-third depth	1.783
From two-thirds depth	1.810
From bottom	1.880
Mean	1.8165

There were three sets of three samples each taken, but one of the samples of one of these sets was missing. The means of the remaining samples gave results as follows:

Percentages of silt at different depths.

	Per cent.
From top	1.764
From mid depth	1.961
From bottom	1.743
Mean	1.8227

Three sets of two samples each yielded the following results:

Percentages of silt at different depths.

	Per cent.
From top	0.474
From bottom	.436
Mean	.455

These results, taken in connection with corresponding results given in the former report, show that as yet no definite conclusions can be drawn regarding the relative percentages of silt carried at different depths in any vertical section.

The results of an attempt to approximate the total quantity of silt carried by the water during the interval covered by this report is given below. In the absence of daily samples at times when the water carried a considerable quantity of sediment, the best that could be done was to attempt to estimate from the samples that were taken what the approximate average was for the interval, the actual measured percentages being interpreted in connection with the daily discharge of the river and the observer's record of the appearance of the water noted daily at the time of taking the gauge height. An attempt was made to make more definite estimates from curves platted from the discharges and the measured percentages of silt at times when samples were taken, but the interval between times of making collections was sometimes too great to allow any reliable estimate to be formed. The curve of discharge and the approximate curve of silt percentages were considered, however, in connection with the other factors stated above, and from these the total silt for each interval was computed and entered

in the table. This total silt is given on the basis of the silt found at the end of one week's settlement:

Estimate of total silt carried by Brazos River.

Date.	Appearance of water.	Discharge.	Silt.	
		Acre-feet.	*Per cent.*	*Acre-feet.*
1900.				
November 1-7	Red	40,363	0.900	363.3
November 8-15	Quite red	151,625	1.900	2,880.9
November 16-30	Light red	64,256	.145	93.2
December 1-31	Clear	77,452	.000	.0
1901.				
January 1-31	....do	52,701	.000	.0
February 1-7	....do	10,737	.000	.0
February 8-15	Cloudy	20,263	.080	16.2
February 16-28	Clear	26,002	.000	.0
March 1-24	....do	35,444	.000	.0
March 25-27	Cloudy	5,611	.123	6.9
March 28-31	Clear	7,197	.000	.0
April 1-3	Slightly muddy	10,598	.150	15.9
April 4-6	Clear	5,822	.000	.0
April 7-10	Cloudy	9,355	.080	7.5
April 11-17	Clear	15,313	.000	.0
April 18-21	Muddy	20,938	.400	83.8
April 22-25	Cloudy	7,890	.080	6.3
April 26-30	Clear	8,192	.000	.0
May 1-6	Cloudy	8,381	.080	6.7
May 7-11	Slightly muddy	14,434	.330	47.6
May 12-18	Clear	7,655	.000	.0
May 19-20	Red	56,776	2.000	1,135.5
May 21-22	....do	55,329	2.700	1,493.9
May 23-24	....do	48,504	1.350	654.8
May 25-31	Dark	90,370	1.150	1,039.3
June 1-3	Light red	28,915	1.100	318.1
June 4-8	Dark red	151,236	3.750	5,671.4
June 9-13	....do	48,164	2.400	1,155.9
June 14-18	....do	22,334	1.800	402.0
June 19-26	Red	18,975	.400	75.9
June 27-30	Faint red	6,436	.300	19.3
July 1-4	....do	6,102	.200	12.2
July 5-31	Clear	22,016	.000	.0
August 1-31	....do	38,104	.000	.0
September 1-15	....do	11,334	.000	.0
September 16-17	Slightly muddy	4,831	.135	6.5
September 18-21	Muddy	13,918	.450	62.6
September 22-25	Slightly muddy	9,392	.250	23.5
September 26-28	Cloudy	4,493	.100	4.5
September 29-30	Clear	2,485	.000	.0
October 1-31	....do	24,717	.000	.0
November 1-30	....do	27,150	.000	.0
December 1-31	....do	18,488	.000	.0
1902.				
January 1-31	....do	14,448	.000	.0
February 1-28	....do	12,944	.000	.0
Total for 16 months		1,337,690		15,603.7

The following table gives the results of silt measurements on the Brazos River for the entire time covered by this investigation:

Summary of silt measurements.

Date.	Total discharge.	Silt, one week's settlement.		Silt, one year's settlement.	
	Acre-feet.	*Acre-feet.*	*Per cent.*	*Acre-feet.*	*Per cent.*
August 1 to December 31, 1899	1,165,300	10,090	0.866	7,567	0.649
January 1 to December 31, 1900	8,806,986	115,782	1.315	86,837	.986
January 1 to December 31, 1901	976,602	12,328	1.262	9,246	.947
Total for 29 months	10,948,888	138,200	1.262	103,650	.947

From the foregoing it is seen that the discharge during 1901 was only about 11 per cent of the discharge during 1900, while the silt discharged during 1901 was a little less than 11 per cent of that discharged during 1900. Inasmuch as the river overflowed during 1900 for considerable periods of time, and because it was impossible to measure that portion of the discharge that was not confined to the river channel, it is probable that for the year 1900 the discharge was fully ten times that for the year 1901, with about the same relative proportions of silt for the two years.

For the twenty-nine months covered, the approximate average percentage of silt at the end of one week's settlement is 1.262 and at the end of one year 0.947, which is the same as the corresponding percentages for 1901, which was a year of unusually small flow.

In another part of this report there will be found a comparison of the percentages of silt by volume as compared with the percentages by weight for the Brazos and two other rivers.

WICHITA RIVER.

The daily gauge heights of the Wichita River have been read on the painted gauge rod attached to the masonry pier of the highway bridge, about one-half mile northwest of Wichita Falls. On account of the constant travel over the highway bridge, and the interruptions caused thereby, current meter measurements were transferred to the Fort Worth and Denver City Railway bridge, a few hundred feet higher up the river, beginning with February 9, 1901.

For the period covered by this report the following discharge measurements were made:

Measured discharge of the Wichita River at Wichita Falls, Tex.

Date.	Gauge height.	Discharge.	Velocities measured by—
	Feet.	*Cu. ft. per sec.*	
February 9, 1901	1.25	38.5	Current meter.
May 11, 1901	1.05	19.7	Do.
May 15, 1901	2.40	451.0	Floats.
May 16, 1901	13.90	19,850.0	Do.
May 17, 1901	19.40	37,440.0	Do.
May 22, 1901, 1.15 p. m.	5.00	2,250.0	Do.
May 22, 1901, 7.50 p. m.	4.60	1,860.0	Do.
August 7, 1901	1.25	71.0	Current meter.

All the float measurements of velocity were made by Mr. N. Wernskiold, of Dallas, who was engineer in charge of the construction of the Holliday Creek irrigation reservoir, near Wichita Falls, at the time. The computations of the discharges were, however, made by the writer from cross sections made by him on May 11 and August 7, 1901, taken in connection with the velocities as determined by Mr. Wernskiold. But for the courtesy of Mr. Wernskiold, who at considerable trouble made the velocity determinations, the discharge at high

stages of the river would have been very uncertain, since the higher points on the rating curve would have had to be determined from discharge measurements made during the previous year. Even as it was, some of these points had to be used for the curve prior to May 16, 1901, namely, the discharges measured on July 21, 1900, at 5.30 p. m., and on September 6, 1900, both of which are given in the progress report made in 1900.

It was found to be impossible to make a single rating curve give even approximately correct results for the whole period because of the very marked change in depth of channel caused by the heavy May rise and also by another rise of small proportions in September, 1901. Three rating curves have accordingly been drawn in the attempt to arrive at something like an approximate value of the discharges during the period covered by this report. The first is for the interval from October 1, 1900, to May 13, 1901; a second rating curve was drawn for the interval between May 14 and September 16, 1901, and a third rating curve was drawn to cover the interval from September 17, 1901, to February 15, 1902.

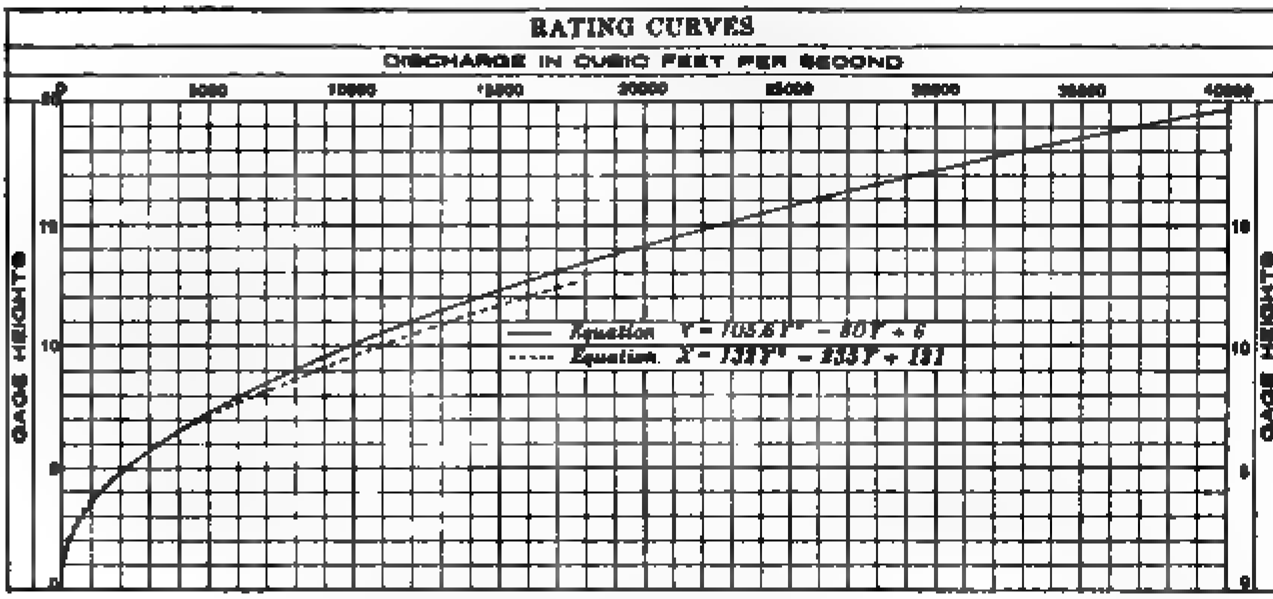
To show the reason for having used different rating curves for the period covered by this report Pl. LXII was drawn. This diagram represents the cross section of the Wichita River at the Fort Worth and Denver City Railway bridge, looking north, or downstream. Only the three cross sections are shown, but they indicate marked changes in the channel by reason of the shifting, unstable character of the material in the bottom.

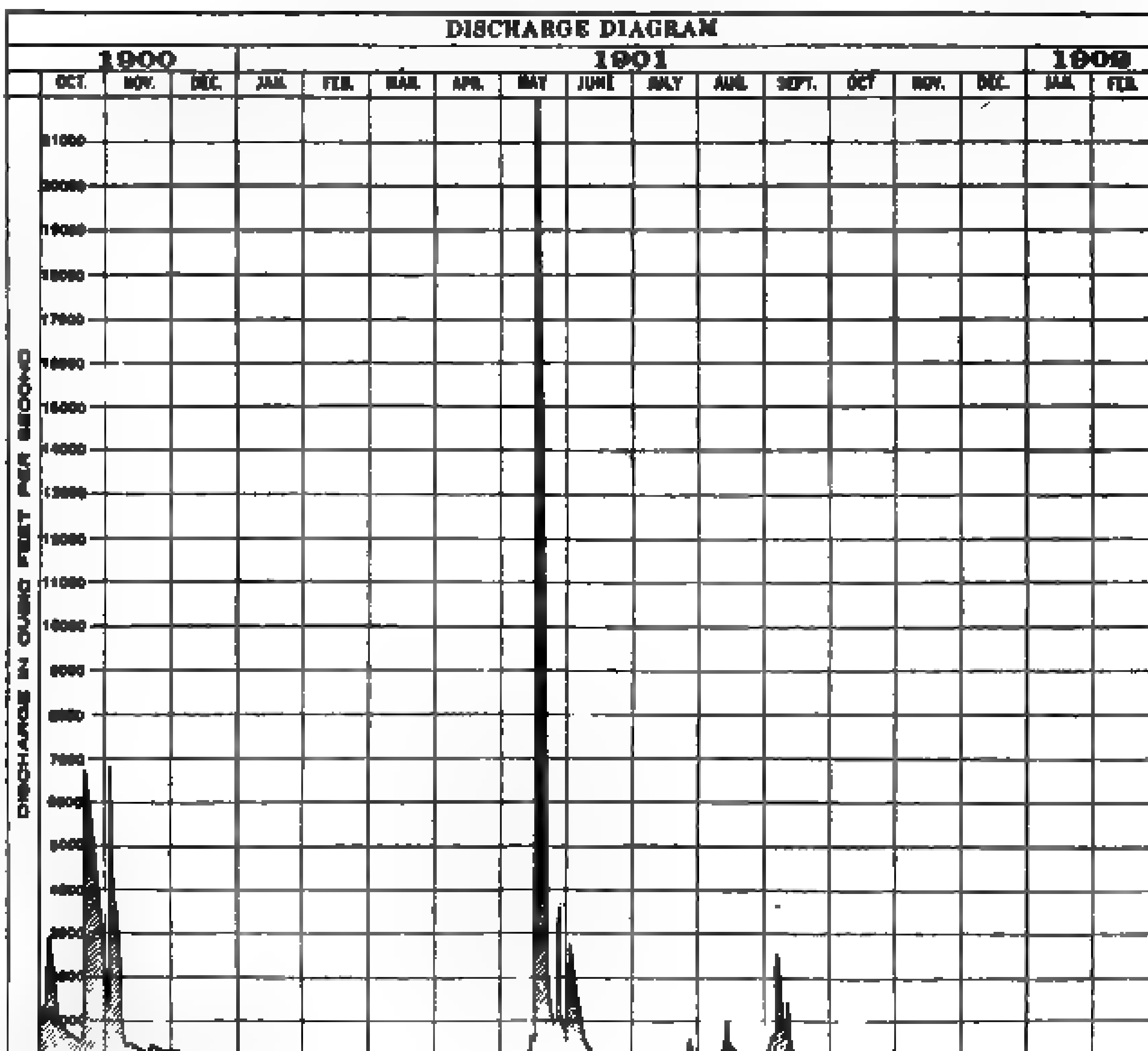
All discharges given for the time after September 17 must be regarded as very unreliable, and are only inserted in order to get some idea of the probable discharge during this period. The total discharge for this time is very small, and forms but a small part of the discharge for the period covered by this report. The time and expense involved in making even a single trip to Wichita Falls would have been greater than the results to be obtained by more accurate measurements would seem to justify as long as the gauge heights, and consequent discharges, were so low.

Pl. LXII shows the three rating curves above mentioned in their relations to the points found by measured discharges, the gauge heights being ordinates, and the discharges, in cubic feet per second, being abscissas.

The table given below shows the discharges in acre-feet per day computed from the rating curves given. While the discharges have been given to final units, this is not intended to convey the impression that the measurements show any such degree of accuracy. The measurements must be considered as approximations, but are close readings from the curves.

DIAGRAMS SHOWING CROSS SECTIONS, RATING CURVES, AND DISCHARGE OF WICHITA RIVER AT WICHITA FALLS.





Discharge of the Wichita River at Wichita Falls, Tex.

Day.	1900.			1901.												1902.	
	October.	November.	December.	January.	February.	March.	April.	May.	June.	July.	August.	September.	October.	November.	December.	January.	February.
	Acre-feet.	Acre-feet.	Acre-feet.	Acre-feet.	Acre-feet.	Acre-feet.	Acre-feet.	Acre-feet.	Acre-feet.	Acre-feet.	Acre-feet.	Acre-feet.	Acre-feet.	Acre-feet.	Acre-feet.	Acre-feet.	Acre-feet.
1	2,083	2,565	448	101	67	40	44	36	4,455	141	246	40	34	12	8	8	10
2	1,864	13,267	417	101	58	40	40	40	4,455	123	222	532	32	10	10	10	8
3	3,074	6,869	355	89	58	40	40	44	4,076	123	200	1,210	34	10	8	8	10
4	4,463	5,841	355	89	58	40	36	44	3,713	123	180	1,420	32	10	10	10	12
5	3,074	4,455	299	89	58	40	36	40	3,203	107	161	837	28	12	12	8	12
6	2,737	4,034	250	101	67	36	36	40	2,434	107	161	4,950	28	10	12	12	10
7	2,281	2,100	204	101	67	36	36	44	1,894	91	141	4,262	28	10	12	12	10
8	1,944	1,430	165	101	67	36	36	44	1,313	91	141	2,579	28	34	12	10	8
9	1,944	1,198	131	101	67	36	36	44	924	91	141	1,533	28	24	14	10	10
10	1,817	988	355	89	89	36	36	40	676	77	141	3,041	24	20	18	10	8
11	1,817	797	355	89	89	36	34	40	532	77	107	1,591	24	20	16	8	8
12	1,682	891	299	77	77	36	34	101	405	63	107	1,063	24	18	18	10	8
13	1,353	797	274	77	77	36	32	131	375	63	2,223	756	24	16	14	8	8
14	1,430	797	250	77	67	34	32	1,311	347	63	881	532	20	18	14	10	8
15	1,311	629	204	77	67	34	32	797	319	63	565	347	20	14	14	8	8
16	1,198	553	204	77	58	34	58	38,835	319	63	347	347	18	14	16	10	....
17	1,198	482	204	77	58	34	58	72,620	294	52	246	202	16	14	18	10	....
18	1,091	417	184	89	58	32	52	34,948	294	52	200	177	18	12	16	10	....
19	988	355	165	89	58	32	44	19,370	294	52	200	129	14	12	18	12	....
20	9,806	988	165	89	77	32	44	14,138	270	52	200	107	14	12	14	12	....
21	13,267	938	165	77	77	32	44	6,600	270	40	180	89	12	12	14	12	....
22	11,819	891	165	77	89	32	40	5,054	246	40	180	79	12	12	12	10	....
23	11,128	797	147	77	77	32	40	2,729	222	40	161	71	12	12	12	8	....
24	9,806	712	131	77	67	32	40	1,708	200	40	161	63	12	10	12	10	....
25	9,177	670	131	77	58	32	36	1,420	200	40	141	58	12	10	10	8	....
26	7,981	629	131	67	58	147	36	2,156	180	40	123	38	12	10	10	10	....
27	7,414	553	131	67	58	131	36	7,079	180	924	91	44	12	12	10	8	....
28	6,343	518	115	67	58	101	36	2,882	161	1,016	77	38	12	10	8	10	....
29	5,841	482	115	67	....	89	36	2,298	161	246	63	34	12	8	10	8	....
30	4,455	482	101	67	....	77	36	1,894	141	246	40	32	12	10	8	10	....
31	3,636	....	101	67	....	58	....	1,420	....	246	40	....	12	....	10	8	....
Total	138,022	56,125	6,716	2,567	1,884	1,483	1,176	217,942	32,553	4,592	8,067	26,201	620	408	390	298	138

The run-off from the drainage area is given also in two ways in the following table: First, in depth in inches; and second, in cubic feet per second. These figures are for a drainage area of 3,050 square miles, the probable area of the watershed, as stated in the 1900 report.

Computed monthly discharge of the Wichita River at Wichita Falls, Tex.

Month.	Mean discharge.	Discharge for month.	Run-off.	
			Depth.	Per square mile.
	Cu.ft.per sec.	*Acre-feet.*	*Inches.*	*Cu.ft.per sec.*
1900.				
October	2,244.7	138,022	0.8485	0.7360
November	943.2	56,125	.3450	.3092
December	109.2	6,716	.0413	.0358
1901.				
January	41.7	2,567	.0158	.0137
February	33.9	1,884	.0116	.0111
March	24.1	1,483	.0091	.0079
April	19.8	1,176	.0072	.0065
May	3,544.5	217,942	1.3398	1.1621
June	547.1	32,553	.2001	.1794
July	74.7	4,592	.0282	.0245
August	131.2	8,067	.0496	.0430
September	440.3	26,201	.1611	.1444
October	10.1	620	.0038	.0033
November	6.8	408	.0025	.0022
December	6.3	390	.0024	.0021
1902.				
January	4.9	298	.0018	.0016
February	[a]4.6	.138	.0008	.0015
Total for 16.5 months	....	499,182	3.0686	....

[a] First 15 days only.

For the whole period covered by the observations at Wichita Falls the discharge and run-off are as follows:

Table showing total discharge and run-off of Wichita River for two years.

Period.	Discharge.	Run-off from 3,050 square miles.	
	Acre-feet.	*Inches.*	*Cu.ft.per sec.*
February 10 to December 31, 1900	842,453	5.1792	0.4281
January 1 to December 31, 1901	297,883	1.8312	.1371
January 1 to February 15, 1902	436	.0027	.0016

If we divide the time covered by all the observations at Wichita Falls in two periods of one year each, beginning with February 10, 1900, and ending with February 9, 1902, we get the following as the discharge for the two periods:

	Acre-feet.
February 10, 1900, to February 9, 1901	845,587
February 10, 1901, to February 9, 1902	295,137

The discharge during the former of these two years was nearly three times what it was during the latter year. Furthermore, it is seen by reference to the table giving discharges that the month of May, 1901, contributed three-fourths of the total discharge occurring between February 10, 1901, and February 10, 1902. If the large irrigation reservoir that has been projected on the Wichita River had

been constructed, there is a probability that it would have been filled only once during 1901, though it would have been full to begin the year with from the rains of 1900. There would, therefore, have been available for irrigation during that season a volume of water equal to at least twice the capacity of the reservoir. The past year was an exceptionally dry one, so that it appears likely that any ordinary year will probably furnish water enough to fill the proposed reservoir of 200,000 acre-feet capacity at least once and possibly twice during the year, should it ever be built. The 1900 report stated that it would probably be filled twice on ordinary years, but, taking the flow for 1901 and considering that three-fourths of this came down at a single flood, it is possible that this statement needs some modification. The writer, however, still inclines to the belief that in ordinary years it would be filled twice.

During the spring of 1901 an irrigation reservoir of about 13,000 acre-feet capacity was constructed on Holliday Creek, about 4 miles south of Wichita Falls. The dam of earth was exceptionally well constructed, and every precaution seemed to have been taken to guard against mishap. At the time of the May flood in the Wichita River the reservoir began to fill rapidly, and on account of the green nature of the embankment was watched closely. The upper face of the dam was protected with riprap, and especial precautions had been taken to prevent leakage around the cast-iron outlet pipes that contained the sluice gates. On May 18, before the water level had reached the crest of the spillway, a jet of water broke through the lower face of the dam, spurting up through about 2 feet of earth on the toe like an artesian well. Every effort was made to stop the leak, but it increased in volume until the dam gave way shortly after midnight, and about 150 feet of the dam finally went out. Investigation showed later that the failure was not due to defective construction, strictly speaking, but to an old prairie dog hole that had been covered up for years and which began above the dam and came out beneath it. It also developed that the land upon which the dam was situated had at one time been the site of a prairie dog village, but had been cultivated for ten or a dozen years and the holes had been filled in for a depth of several feet, so were not discovered, though diligent search had been made before the dam was begun. The break has been repaired, but since this was done the rains have been so light that the reservoir has not been filled.

The percentages of silt carried by the Wichita River water from January 1, 1900, to February 15, 1902, as determined by the samples taken on the dates given are shown below. The last sample for which silt determinations were given in the 1900 report was collected on September 6, 1900. During the interval between this date and January 1, 1901, frequent samples were taken, but the observer failed to take proper precautions with them and they were all frozen and the bottles broken during the blizzard in the latter part of December, 1900.

Silt determinations for the Wichita River.

When collected.	Silt in water. Surface.	Mid depth.	Bottom.	Mean.	Discharge.	Total silt.	Appearance of water.	Time required to settle clear.
1901.	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Cu. ft. per sec.*	*Cu. ft. per sec.*		*Hours.*
January 1	0.000	0.000	0.000	0.000	51	0.0	Clear	
January 15	.000	.000	.000	.000	39	0.0	do	
February 2		.000		.000	29	0.0	do	
February 9		.000		.000	34	0.0	do	
February 16		.000		.000	29	0.0	do	
February 23		.000		.000	39	0.0	do	
March 2		.000		.000	20	0.0	do	
March 9		.000		.000	18	0.0	do	
March 16		Trace.	.000	Trace.	17	0.0	do	
March 23		.000		.000	16	0.0	do	
March 30		Trace.		Trace.	39	0.0	do	
April 6		.000		.000	18	0.0	do	
April 13		Trace.		Trace.	16	0.0	do	
April 20		.000		.000	22	0.0	do	
April 27		Trace.		Trace.	18	0.0	do	
May 4		.000		.000	22	0.0	do	
May 11	.000	.000	.000	.000	20	0.0	do	
May 14	.081	Spoiled.	.093	.087	661	0.6	Light red	3
May 17	2.507	2.385	2.423	2.438	36,620	892.8	Very red	3½
May 18	1.806	1.643	1.719	1.723	17,620	303.6	Red	3¼
May 25		.172		.172	716	1.2	Light red	5
June 1	1.996		1.934	1.965	2,246	44.1	Red	4
June 8		.105		.105	662	0.7	Almost clear	4
June 15		.000		.000	161	0.0	Clear	
June 22		.000		.000	124	0.0	do	
June 29		.000		.000	81	0.0	do	
July 6		Trace.		Trace.	54	0.0	do	
July 13		.000		.000	32	0.0	do	
July 20		.000		.000	26	0.0	do	
July 27		Trace.		Trace.	466	0.0	Cloudy	
August 4		.000		.000	91	0.0	Clear	
August 11		.000		.000	54	0.0	do	
August 18		Trace.		Trace.	101	0.0	do	
August 25		.031		.031	71	0.0	Nearly clear	3
September 1		.000		.000	20	0.0	Clear	
September 7	3.184		3.130	3.157	2,149	67.8	Red	3
September 14		.163		.163	268	0.4	Almost clear	4
September 21		.000		.000	45	0.0	Clear	
September 28		.000		.000	19	0.0	do	
October 5		.000		.000	14	0.0	do	
October 12		.000		.000	12	0.0	do	
October 19		.000		.000	7	0.0	do	
October 26		.000		.000	6	0.0	do	
November 2		.000		.000	5	0.0	do	
November 9		.000		.000	12	0.0	do	
November 16		.000		.000	7	0.0	do	
November 23		.000		.000	6	0.0	do	
November 30		.000		.000	5	0.0	do	
December 7		.000		.000	6	0.0	do	
December 14		.000		.000	7	0.0	do	
December 21		.000		.000	7	0.0	do	
December 28		.000		.000	4	0.0	do	
1902.								
January 4		.000		.000	4	0.0	do	
January 11		.000		.000	4	0.0	do	
January 18		.000		.000	5	0.0	do	
January 25		.000		.000	4	0.0	do	
February 1		.000		.000	5	0.0	do	
February 8		.000		.000	4	0.0	do	
February 15		.000		.000	4	0.0	do	

The observer's record shows that from November 10 to December 31, 1900, the water was clear, so that the total gap for which samples would have been of real value is the time intervening between the taking of the last sample in September, 1900, until November 10—about two months.

The table shows that all the samples taken during 1901 prior to May 14 were without appreciable sediment, and that there were only two rises during this year that brought down measurable quantities of

silt—the one which began about the middle of May and the one that occurred in September. Moreover the percentage of silt in any sample was less during the time covered by this report than during the time covered by the 1900 report. Nevertheless, the mean percentage of silt coming down during 1901 will be found to be larger than that coming during 1900, because of the much larger relative value of the volume of flood flow in 1901 than in 1900, as compared with the total discharge.

For some reason the observer failed to collect four samples for each set at times when the water was heavily charged with silt. Only four sets of three each were taken, and one of the samples in one of these sets was spoiled when it reached the writer. The means of the two remaining sets of three each are as follows:

Percentage of silt at different depths.

	Per cent.
From top	2.157
From mid depth	2.014
From bottom	2.071
Mean	2.081

Only two sets of two each were taken, and for them we have the following results:

Percentage of silt at different depths.

	Per cent.
From top	2.590
From bottom	2.532
Mean	2.561

In both these results the top samples carried the largest percentage of silt, but taken in connection with the results shown in the 1900 report, and considering the small number of samples involved, no conclusions regarding the distribution of silt in any vertical plane can be reached unless it be that there is no definite law relating to such distribution.

The next table gives the results of an attempt to arrive at an approximate estimate of the total quantity of silt carried during the interval over which the report extends. As has been stated, all samples taken before January 1, 1901, and after September 6, 1900, were frozen and the water lost through the breaking of the bottles before the percentages of silt had been determined. For this portion of the time, therefore, reliance had to be placed in the observer's daily record, together with the computed discharges taken in connection with corresponding discharges for which the percentage of silt had been determined. From October 1 to November 10, 1900, the observer's record shows that the water was clear, hence the element of uncertainty applies more particularly to figures given for October and the first third of November.

Estimate of total silt carried by the Wichita River.

Date.	Appearance of water.	Discharge.	Silt.	
		Acre-feet.	*Per cent.*	*Acre-feet.*
1900.				
October 1-8	Slightly red	21,520	0.500	107.6
October 9-19	Nearly clear	15,829	.050	7.9
October 20-25	Red	65,003	2.100	1,365.1
October 26-31	do	35,670	1.400	499.4
November 1	Light red	2,565	.800	20.5
November 2-6	Red	34,466	1.800	620.4
November 7-9	Light red	4,728	.800	37.8
November 10-30	Clear	14,366		
December 1-31	do	6,716		
1901.				
January 1-31	Clear	2,567		
February 1-28	do	1,884		
March 1-25	do	880		
March 26-31	Slightly red	603	.050	.3
April 1-30	Clear	1,176		
May 1-13	do	688		
May 14-15	Light red	2,108	.085	1.8
May 16-17	Very red	111,455	2.400	2,674.[illegible]
May 18-19	do	54,318	1.700	923.[illegible]
May 20-22	Red	25,792	.800	206.[illegible]
May 23-26	Light red	8,013	.200	16.0
May 27-29	Red	12,254	1.000	122.[illegible]
May 30-31	Slightly red	3,314	.200	6.[illegible]
June 1-2	Very red	8,910	1.950	173.7
June 3-5	Light red	10,992	.900	98.9
June 6-10	Nearly clear	7,241	.120	8.7
June 11-30	Clear	5,410		
July 1-31	do	4,592		
August 1-12	do	1,948		
August 13-16	Slightly red	4,016	.100	4.0
August 17-27	Nearly clear	1,883	.040	.8
August 28-31	Clear	220		
September 1	do	40		
September 2-5	Slightly red	3,999	.200	8.0
September 6-7	Very red	9,212	3.160	291.[illegible]
September 8-12	Red	9,807	1.000	98.1
September 13-16	Slightly red	1,982	.200	4.0
September 17-30	Clear	1,161		
October 1-31	do	620		
November 1-30	do	408		
December 1-30	do	390		
1902.				
January 1-31	do	298		
February 1-15	do	138		
For 16½ months		499,182	1.462	7,298.0

The following table gives the results of all the measurements made on the Wichita River:

Summary of silt measurements.

Date.	Total discharge.	Silt, one week's settlement.		Silt, one year's settlement.	
	Acre-feet.	*Acre-feet.*	*Per cent.*	*Acre-feet.*	*Per cent.*
February 10 to December 31, 1900	842,453	10,171.5	1.207	7,628.6	0.906
January 1 to December 31, 1901	297,883	4,639.3	1.557	3,479.5	1.168

While the amount of water discharged during 1900 was a little more than 2.8 times as much as during 1901 the estimated amount of sediment for the former year was a little less than 2.2 times as much as for the latter year. For 1900 the probable average percentage of silt at the end of one week's settlement was 1.207 and at the end of a year's settlement it was 0.906. For 1901 the probable percentage of silt at the end of one week's settlement was 1.557 and at the end of a year's settlement it was 1.168. Thus it might appear at first sight that

for 1901 the effect upon an irrigation reservoir would be more harmful than during the preceding year of much heavier rainfall. This would scarcely be the case, however, for all the silt carried by the water for both years would have to pass into or through the reservoir and because of the reduced velocity through the reservoir much of it would be there precipitated. The silt carried at high stages appears to go to the bottom very rapidly in quiet or comparatively quiet water, so that it is more than likely that a larger amount would be left in the reservoir during a year of high discharge, such as 1900 was, than would be the case for a year of smaller discharge but higher percentage of silt in the water, as was the case for 1901.

The results of the two years' observations on the Wichita River show conclusively that the question of the silting up of an impounding reservoir on that river is one of the most serious problems that must be solved. The reservoir projected above Wichita Falls will have a storage capacity of 200,000 acre-feet, according to the plans that have been prepared, and if all the silt that has come down during the two years over which observations were carried should be deposited above the dam the life of that reservoir would be comparatively short. As computed for a period of one year's settlement the total silt for two years was something like 11,000 acre-feet—more than one-twentieth of the original capacity of the reservoir. Of course, the rate of precipitation of the silt would decrease as the capacity of the reservoir became reduced, for a larger portion of the water at flood tide would pass through the reservoir, carrying with it a portion of the sediment, but as long as the cross section of the reservoir was greater than the normal cross section of the river some, at least, of that sediment would go to the bottom. Unless some plan can be devised whereby the silt can be kept from filling up the reservoir the only feasible plan apparent would be to so construct the dam in the first place that when the capacity of the reservoir becomes too much reduced to serve the land below the dam the latter could be built higher and a new storage space made available. However, the conditions in the Wichita Valley appear to be so favorable for irrigation that with due regard to economical construction and operation the system could be made to pay for itself before the storage capacity had been too greatly reduced by the accumulation of silt in the reservoir, even though no provisions were made for increasing the capacity subsequent to the original construction.

RIO GRANDE.

A few samples of water from the Rio Grande that were collected at El Paso, Tex., under direction of the consulting engineer of the International (Water) Boundary Commission, Mr. P. D. Cunningham, working in line with an arrangement made with his predecessor, Mr. W. W. Follett, were received by the writer after the completion of

the 1900 report, and the results of volumetric determinations of the sediment they contained will be found below. These samples are very highly charged with silt, and Mr. Follett states that they were taken from the flow of a sudden flood which followed a period of two months in which the river was dry. As this report is being written a number of other samples that were collected during the late spring of 1901, at a time of steady flow in the river, have just been received. No determinations have as yet been made upon them, but, by inspection, the samples indicate much smaller quantities of silt than those given in the table.

Silt determinations for the Rio Grande at El Paso, Tex.

When collected.	Silt in water at end of— 7 days.	33 days.	71 days.	182 days.	Discharge.	Total silt for one week's settlement.	Time required to settle clear.	Appearance of deposit.
	Per cent.	*Per cent.*	*Per cent.*	*Per cent.*	*Cu. ft. per sec.*	*Cu. ft. per sec.*	*Hours.*	
1900.								
September 9, 9.30 a. m.	8.488	7.347	7.160	6.897	1,160	98.5	12	Black.
September 9, 6 p. m.	22.400	20.300	18.220	16.050	500	112.0	6	Light brown.
September 13, 8.45 a. m.	15.743	14.577	13.577	13.120	2,000	314.9	6	Do.
September 13, 5.40 p. m.	17.673	16.150	14.800	13.500	1,380	243.9	6	Do.
September 15, 8 a. m.	18.405	15.950	15.020	14.600	900	165.6	6	Upper one-fifth light brown, balance dark brown.
September 18, 5.50 p. m.	17.742	15.548	14.677	14.032	600	106.5	6	Do.
September 20, 7.50 a. m.	33.217	27.622	25.524	24.825	160	53.1	6	Upper one-fifth light brown, balance quite dark.
September 24, 8 a. m.	12.812	10.313	9.688	9.063	45	5.8	6	Upper one-third light brown, balance slightly darker.
Mean	18.310	15.976	14.833	14.011	....	....	....	

It will be observed that the settlement was continued for one hundred and thirty-two days, at the end of which time the settling tubes had to be used for other samples. The volumes of silt were read at the end of seven days, at thirty-three days, at seventy-one days, and again at one hundred and thirty-two days, and showed continuous shrinking. At the end of thirty-three days they had decreased, on the average, about one-eighth of what they had been at seven days. At one hundred and thirty-two days the volumes averaged about 23.5 per cent less than they did at the end of seven days. Many of the samples showed a difference in the source from which certain parts of the sediment had come. The last four showed two distinct layers in the settling tubes, the upper of light-brown color, the lower of a much darker shade. The upper layer was evidently much more finely divided and was the last to come down, though practically all of it had settled out at the end of six hours.

The discharges in cubic feet per second, corresponding to the hours at which the samples were collected, were furnished to the writer by

Mr. Follett. From these and the percentages at the end of one week's settlement the number of cubic feet per second of silt carried were computed and entered in the seventh column. The first two samples given show the striking differences that may appear in samples collected at different hours on the same day, the appearance of the sediment being different, however, indicating that the bulk of the flood waters did not originate at the same place.

COMPARISON OF SILT DETERMINATIONS BY VOLUME AND BY WEIGHT.

In order to gain some idea of the relation between the percentages of silt in the waters as determined by volume and by weight, a number of samples from the Brazos, the Wichita, and the Rio Grande were turned over to the assistant chemist of the Texas Agricultural Experiment Station, Mr W. C. Martin, for determination by weight. Mr. Martin was given a leave of absence for one year before completing the work, and Mr. W. J. Walden, fellow in chemistry in the Agricultural and Mechanical College of Texas, completed the work begun by Mr. Martin. In fact, the larger part of the work was done by Mr. Walden.

The percentages by weight were determined by taking a given quantity of the well-shaken water and filtering it through a Gooch crucible until the effluent was clear, then drying the sediment and weighing it. When the amount of sediment in the water was not greater than about 3 per cent, as determined by volumetric measurements at the end of one week, the quantity of water taken was found by measurement in a pipette; but when the amount of silt was quite large the weight of water was determined by the balance. For the Brazos River samples were taken that had been collected on nine different dates, in all twenty-six bottles. For the Wichita River samples were taken that were collected on five different dates, or nine different bottles. For the Rio Grande eight samples were taken that had been collected on six different days, though no two samples were collected at the same hour. The results of these determinations are shown in the table which follows:

Comparison of sediment determinations by volume and by weight.

Where and when collected.	Relative depth.	Percentage. By volume, end of one week.	Percentage. By weight.	Ratio.
Brazos River at Jones Bridge:				
May 9, 1901	Middle	0.398	0.108	3.685
May 19, 1901	Top	2.070	.812	2.550
	One-third	1.950	.712	2.739
	Two-thirds	2.080	1.061	1.961
	Mean	2.033	.862	2.359

Comparison of sediment determinations by volume and by weight—Continued.

Where and when collected.	Relative depth.	Percentage. By volume, end of one week.	Percentage. By weight.	Ratio.
Brazos River at Jones Bridge—Continued.				
May 21, 1901	Top	2.840	0.926	3.067
	One-third	2.780	.933	2.980
	Two-thirds	2.770	.926	2.991
	Bottom	2.750	.978	2.812
	Mean	2.785	.941	2.960
May 24, 1901	Top	1.250	.620	2.015
	One-third	1.290	.621	2.077
	Two-thirds	1.410	.698	2.020
	Bottom	1.450	.593	2.446
	Mean	1.350	.633	2.133
May 25, 1901	Top	1.290	.468	2.756
	One-third	1.280	.476	2.689
	Two-thirds	1.250	.482	2.594
	Bottom	1.440	.550	2.618
	Mean	1.315	.494	2.662
June 2, 1901	Top	1.325	.269	4.926
	Middle	.834	.257	3.245
	Bottom	1.105	.269	4.107
	Mean	1.088	.265	4.106
June 6, 1901	One-third	3.820	1.045	3.656
	Two-thirds	3.467	.784	4.422
	Bottom	4.000	1.345	2.974
	Mean	3.762	1.058	3.556
June 10, 1901	Top	2.202	.670	3.286
	Middle	3.088	.704	4.387
	Bottom	2.380	.765	3.111
	Mean	2.557	.713	3.587
June 16, 1901	Middle	1.810	.478	3.787
Mean for Brazos River		1.900	.617	3.080
Wichita River at Wichita Falls:				
May 14, 1901	Middle	.093	.052	1.788
May 17, 1901	Top	2.507	1.215	2.063
	Middle	2.385	1.117	2.135
	Bottom	2.423	1.157	2.094
	Mean	2.438	1.163	2.096
May 18, 1901	Top	1.806	.908	1.989
	Middle	1.643	.908	1.809
	Bottom	1.719	.911	1.887
	Mean	1.723	.909	1.895
June 1, 1901	Top	1.996	.723	2.761
	Bottom	1.934	.658	2.939
	Mean	1.965	.691	2.844
Mean for Wichita River		1.555	.704	2.210
Rio Grande at El Paso:				
Sept. 9, 1900, 8.30 a. m.		8.488	3.971	2.138
Sept. 9, 1900, 6.00 p. m.		22.400	5.525	4.054
Sept. 13, 1900, 8.45 a. m.		15.743	3.700	4.255
Sept. 13, 1900, 5.40 p. m.		17.673	4.290	4.119
Sept. 15, 1900, 8.00 a. m.		18.405	5.150	3.574
Sept. 18, 1900, 5.50 p. m.		17.742	4.900	3.621
Sept. 20, 1900, 7.50 a. m.		33.217	8.658	3.836
Sept. 24, 1900, 8.00 a. m.		12.812	3.372	3.799
Mean for Rio Grande		18.310	4.946	3.702

The table shows that for the different samples of each set a fairly uniform ratio between percentages by volume and by weight obtains, though there are some marked deviations from uniformity, as for the Brazos River samples collected on May 19, June 2, June 6, and June 10, 1901. The ratio for one week's settlement in determining the percentage volumetrically is, on the average, as follows:

For the Brazos	3.080
For the Wichita	2.210
For the Rio Grande	3.702

For the volumes as determined at the end of one year's settlement the ratios between such probable percentages and the percentages by weight for the three rivers considered are as follows:

For the Brazos	1.53
For the Wichita	1.66
For the Rio Grande	2.83

From the foregoing it is seen that to determine the volume of silt carried by a given river water by weight only, and then to compute the quantity of this sediment from the weight of a cubic unit of dried sediment will always give results that are too small, and hence misleading if employed in attempting to determine the rate at which a reservoir on such a stream would probably fill up.

DISCHARGE MEASUREMENTS ON THE BRAZOS AND COLORADO RIVERS IN THE TEXAS RICE BELT.

NECESSITY FOR THE MEASUREMENT.

In the last few years a large acreage has been planted in rice, principally in the eastern part of the Texas coastal plain. During the last two years particularly the cultivation of rice has been extended westward even beyond the Lower Colorado bottom. On this river from the neighborhood of Columbus southward the industry has grown at a very rapid rate, so rapid, in fact, that there is serious danger that the supply of water will not suffice to meet the demand made upon it. The lands adjacent to the Brazos River along its lower reaches are also coming into use for rice planting, so it was thought advisable to secure information regarding the amount of water available for that purpose during the irrigation season from this river as well as from the Colorado. June 14, 1901, the writer made a trip to Richmond and Wharton and established gauging stations on the Brazos and Colorado rivers at these points, at which stations observations were continued until November 3. It would have been desirable to have had the work begin earlier, but it was inconvenient to do so. Moreover, the amount of irrigation needed prior to that time is not great enough to threaten exhaustion of the supply at an earlier date.

Only four discharge measurements were obtained at each of the stations, and these were not as well distributed as regards gauge heights

as could have been desired, but because of the sudden changes in the water level of the Colorado River and the distance to be traveled the writer was unable to secure measurements at more suitable stages.

THE BRAZOS RIVER AT RICHMOND, TEX.

Below the gauging station at Jones Bridge and above Richmond. the Yegua and the Navasota rivers empty into the Brazos, as do also a number of small creeks. The precipitation increases also as the Gulf coast is approached, so that at Richmond the discharge is always considerably greater than at Jones Bridge; for this reason the discharge at the latter point gives no direct measure of the discharge at Richmond.

Four discharge measurements were made at Richmond with the following results:

Measured discharges of the Brazos River at Richmond, Tex.

Date.	Gauge height.	Discharge.	Velocities measured by—
	Feet.	*Cu. ft. per sec.*	
June 15, 1901	6.05	4.893	Current meter.
July 24, 1901	1.50	.885	Do.
August 23, 1901	2.00	1.250	Do.
November 2, 1901	1.40	.814	Do.

The zero of the gauge was taken 50 feet below the top of the guard rail of the Southern Pacific Railway Company's bridge at Richmond.

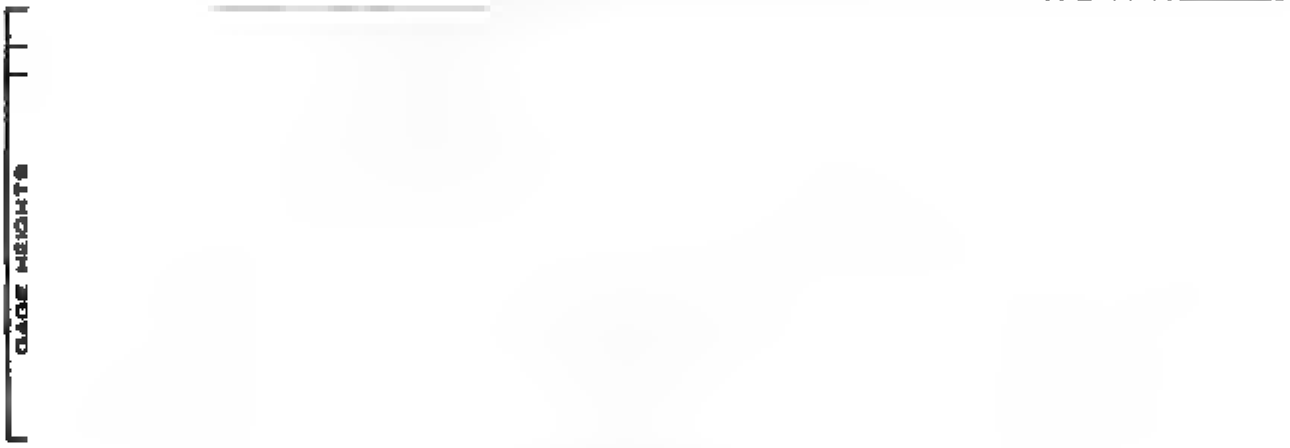
The discharge curve made from the above measurements is shown in Pl. LXIII, the gauge heights being ordinates and discharges in cubic feet per second abscissas. The rating table computed from the curve follows.

Rating table for the Brazos River at Richmond, Tex., from June 14, 1901, to November 3, 1901, inclusive.

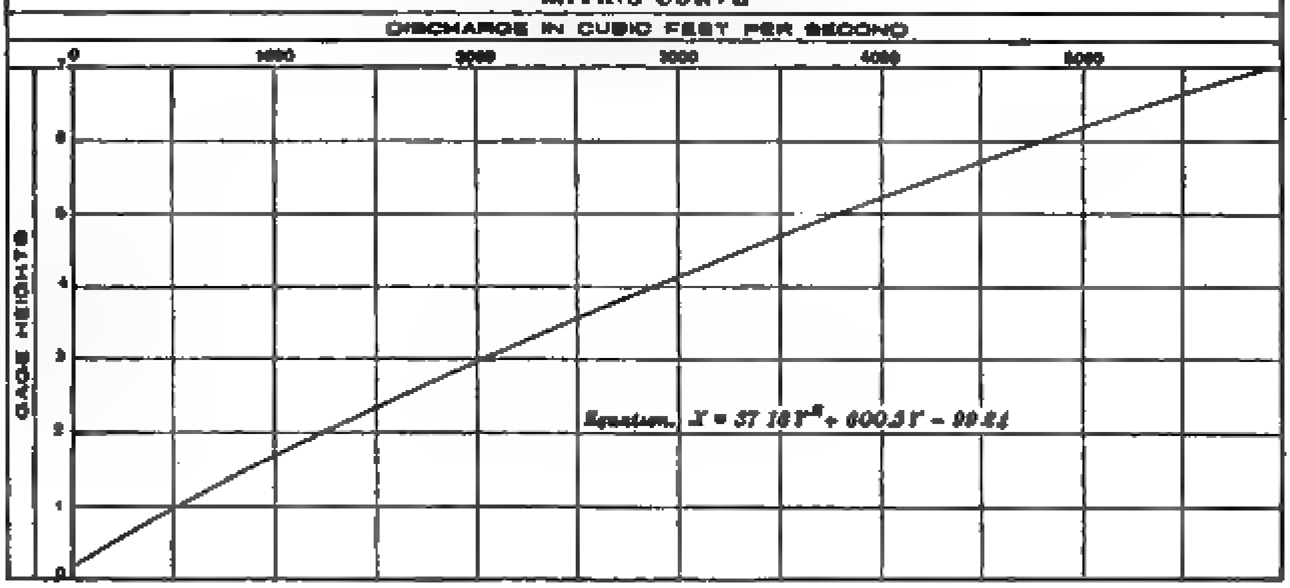
Gauge height.	Discharge.	Gauge height.	Discharge.	Gauge height.	Discharge.
Feet.	*Cu.ft.pr.sec.*	*Feet.*	*Cu.ft.pr.sec.*	*Feet.*	*Cu.ft.pr.sec.*
1.0	538	3.0	2,036	5.0	3,831
1.1	606	3.1	2,119	5.1	3,929
1.2	675	3.2	2,202	5.2	4,027
1.3	744	3.3	2,286	5.3	4,126
1.4	814	3.4	2,371	5.4	4,226
1.5	885	3.5	2,457	5.5	4,327
1.6	956	3.6	2,543	5.6	4,429
1.7	1,029	3.7	2,631	5.7	4,530
1.8	1,102	3.8	2,718	5.8	4,632
1.9	1,176	3.9	2,807	5.9	4,736
2.0	1,250	4.0	2,897	6.0	4,840
2.1	1,325	4.1	2,987	6.1	4,945
2.2	1,401	4.2	3,078	6.2	5,051
2.3	1,478	4.3	3,169	6.3	5,158
2.4	1,556	4.4	3,261	6.4	5,265
2.5	1,634	4.5	3,355	6.5	5,373
2.6	1,713	4.6	3,448	6.6	5,481
2.7	1,792	4.7	3,543	6.7	5,591
2.8	1,873	4.8	3,638	6.8	5,701
2.9	1,954	4.9	3,734	6.9	5,811

The daily gauge heights from June 14 to November 3, 1901, are shown in the following table.

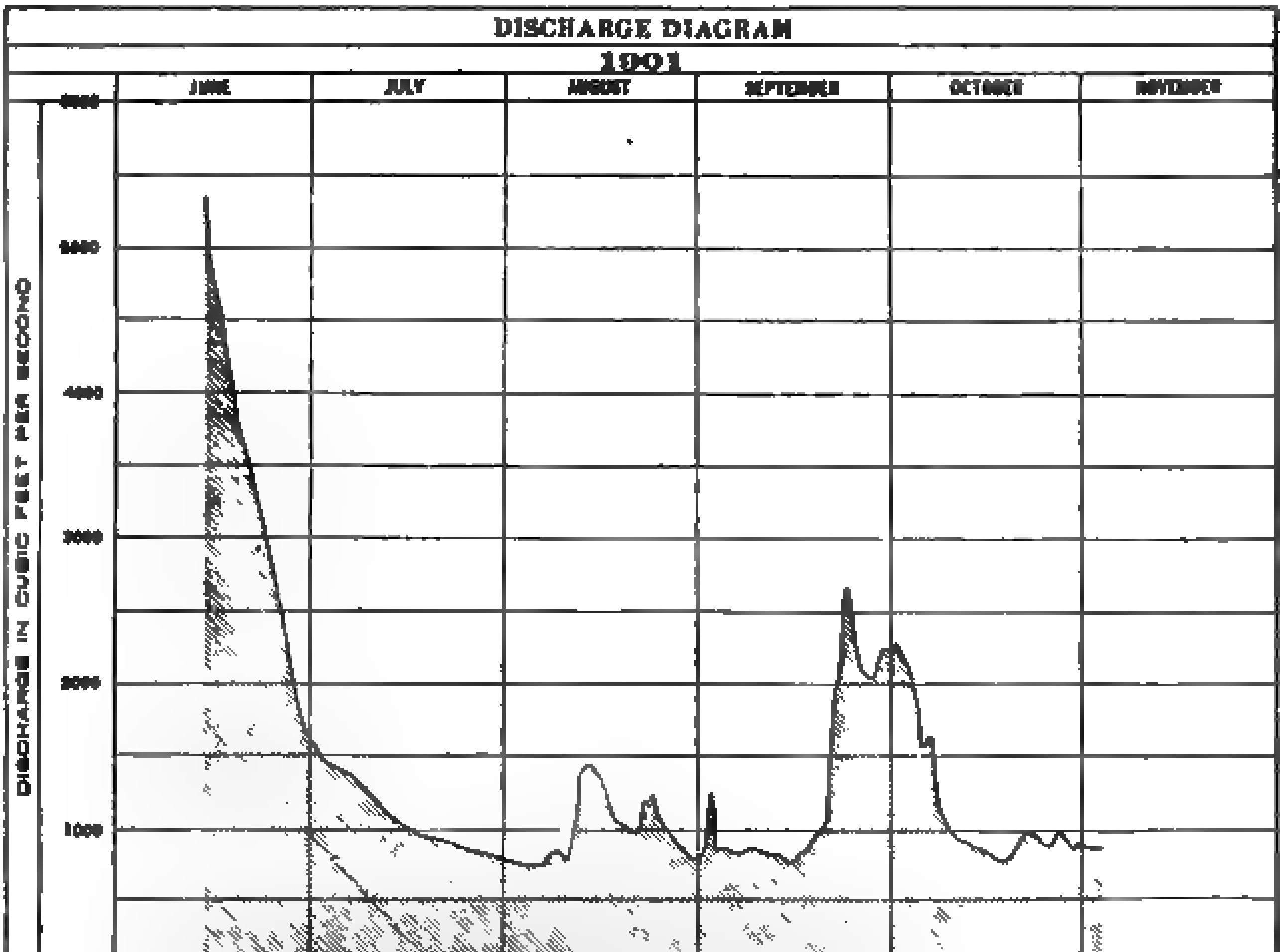
DIAGRAMS SHOWING CROSS SECTIONS, RATING CURVE, AND DISCHARGE OF BRAZOS RIVER AT RICHMOND.



RATING CURVE



DISCHARGE DIAGRAM



Gauge heights of the Brazos River at Richmond, Tex.

Day.	1901.					
	June.	July.	August.	September.	October.	November.
	Feet.	*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*
1	....	2.40	1.30	1.40	3.25	1.40
2	....	2.30	1.30	2.00	3.15	1.40
3	....	2.25	1.30	1.40	3.00	1.40
4	....	2.25	1.30	1.50	2.75	....
5	....	2.20	1.25	1.45	2.40	....
6	....	2.20	1.30	1.40	2.50	....
7	....	2.15	1.30	1.40	1.90	....
8	....	2.10	1.40	1.45	1.85	....
9	....	2.05	1.40	1.45	1.70	....
10	....	1.95	1.35	1.40	1.60	....
11	....	1.85	1.60	1.40	1.60	....
12	....	1.80	2.10	1.40	1.60	....
13	....	1.75	2.30	1.35	1.50	....
14	6.50	1.75	2.20	1.35	1.50	....
15	6.05	1.70	2.00	1.45	1.45	....
16	5.85	1.65	1.90	1.45	1.40	....
17	5.65	1.60	1.80	1.55	1.35	....
18	5.25	1.60	1.70	1.65	1.35	....
19	5.00	1.60	1.70	1.65	1.35	....
20	4.85	1.55	1.65	1.85	1.45	....
21	4.65	1.55	1.65	2.50	1.65	....
22	4.40	1.55	2.00	3.00	1.65	....
23	4.20	1.50	2.00	3.70	1.50	....
24	3.95	1.50	1.75	3.35	1.40	....
25	3.70	1.50	1.70	3.10	1.45	....
26	3.50	1.45	1.55	2.09	1.65	....
27	3.20	1.45	1.50	2.00	1.55	....
28	2.95	1.40	1.45	3.20	1.50	....
29	2.65	1.40	1.40	3.20	1.40	....
30	2.50	1.35	1.35	3.20	1.50	....
31	....	1.35	1.35	....	1.45	....

The above tables taken together were employed in determining the daily discharge in acre-feet. The results of the computations are shown in the table.

Discharge of the Brazos River at Richmond, Tex.

Day.	1901.					
	June.	July.	August.	September.	October.	November.
	Acre-feet.	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*
1	....	3,086	1,476	1,615	4,451	1,615
2	....	2,932	1,476	2,479	4,284	1,615
3	....	2,876	1,476	1,615	4,038	1,615
4	....	2,876	1,476	1,755	3,636	....
5	....	2,779	1,406	1,684	3,086	....
6	....	2,779	1,476	1,615	3,241	....
7	....	2,704	1,476	1,615	2,333	....
8	....	2,628	1,615	1,684	2,259	....
9	....	2,555	1,615	1,684	2,041	....
10	....	2,406	1,545	1,615	1,896	....
11	....	2,259	1,896	1,615	1,896	....
12	....	2,186	2,628	1,615	1,896	....
13	....	2,112	2,932	1,545	1,755	....
14	10,657	2,112	2,779	1,545	1,755	....
15	9,705	2,041	2,479	1,684	1,684	....
16	9,290	1,968	2,333	1,684	1,615	....
17	8,883	1,896	2,186	1,827	1,545	....
18	8,076	1,896	2,041	1,968	1,545	....
19	7,598	1,896	2,041	1,968	1,545	....
20	7,311	1,827	1,968	2,259	1,684	....
21	6,934	1,827	1,968	3,241	1,968	....
22	6,470	1,827	2,479	4,038	1,968	....
23	6,105	1,755	2,479	5,218	1,755	....
24	5,657	1,755	2,112	4,620	1,615	....
25	5,218	1,755	2,041	4,203	1,684	....
26	4,873	1,684	1,827	4,038	1,968	....
27	4,368	1,684	1,755	4,038	1,827	....
28	3,957	1,615	1,684	4,368	1,755	....
29	3,477	1,615	1,615	4,368	1,615	....
30	3,241	1,545	1,545	4,368	1,755	....
31	....	1,545	1,545	....	1,684	....
Total	111,820	66,421	59,370	77,571	67,779	4,845

The changes in the cross section of the river for the time covered by the observations are shown in Pl. LXIII, and indicate that after the June rise had subsided the bottom silted up gradually, but only to a small extent. When it is remembered that during the overflow of 1899 the water level came up almost to the bridge chords, the comparatively slight changes which occurred in nearly five months are apparent.

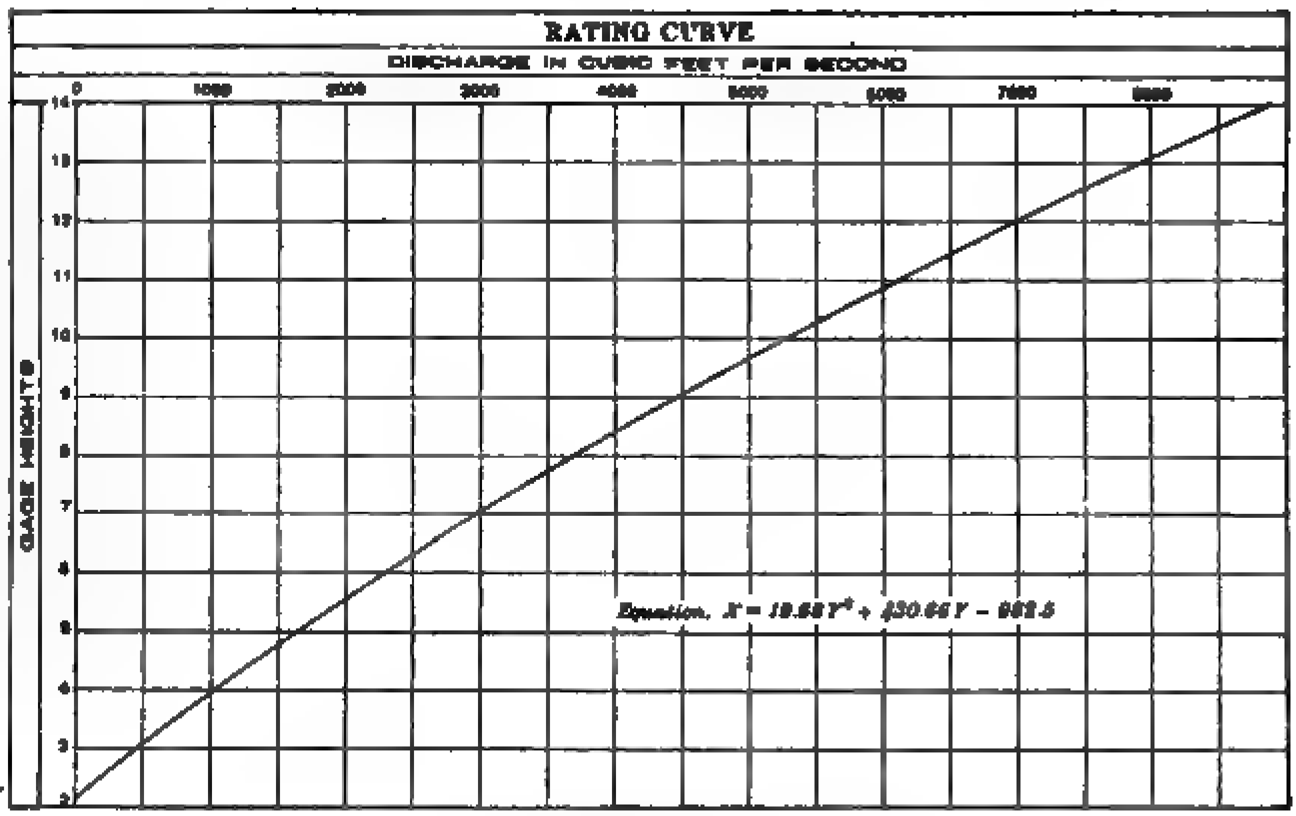
The smallest discharge during the period from June 14 to November 3 occurred on August 5, and was a little over 700 cubic feet per second. As yet no very large acreage of rice has been brought under cultivation below Richmond, but the conditions are as favorable for such operations there as they are at many other places, so that it is probable that the cereal will be extensively grown along this river in the course of a few years. The chief obstacle seems to be the high head that the pumps have to work against at low stages of the water in order to lift the water from the river to the canals. However, higher lifts have been profitably worked in eastern Texas, and there seems to be no good reason why this could not also be done on the Brazos; in fact, it will soon be done by at least one large system.

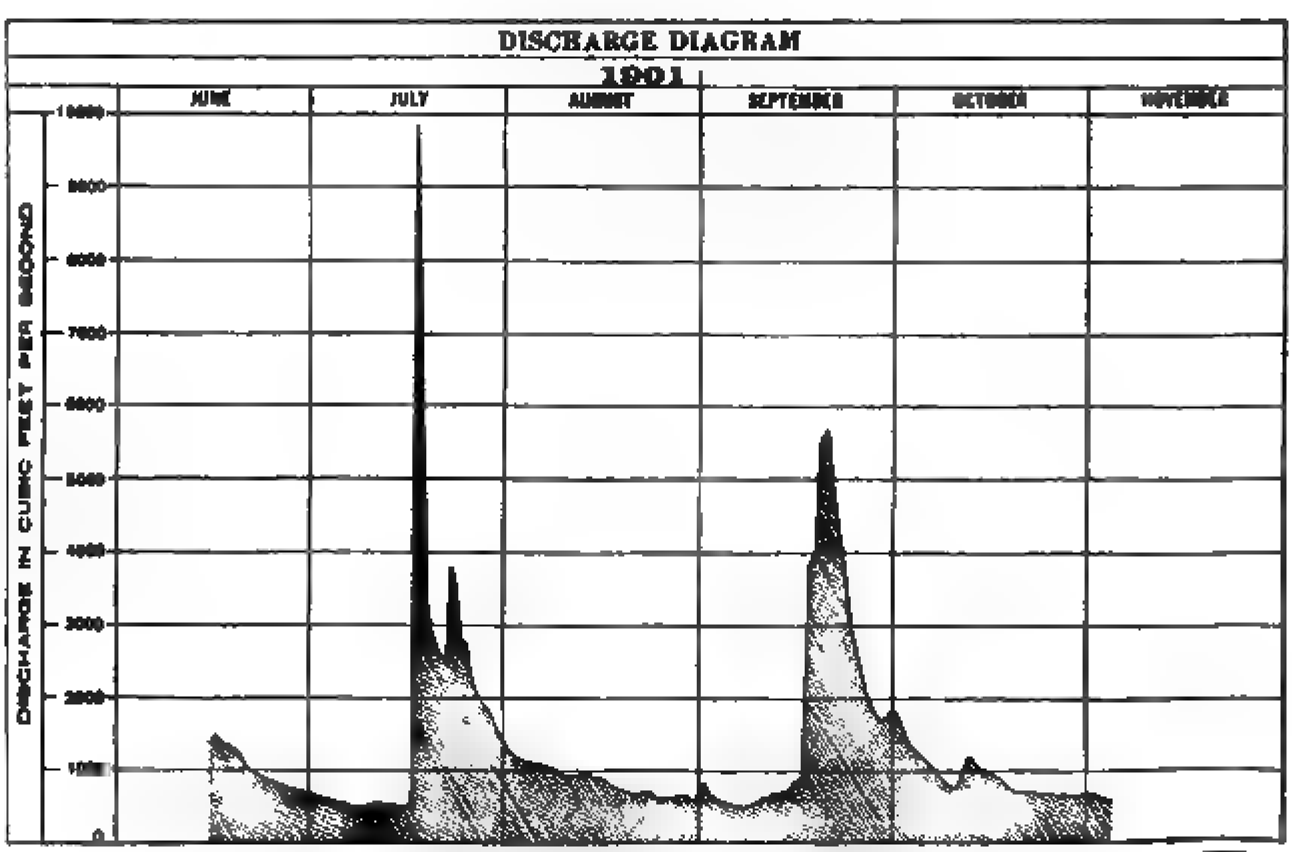
No very definite information regarding the duty of water for rice irrigation is available. The estimates given in response to inquiries regarding practice in this matter varied anywhere from 13 gallons per acre per minute to 6 gallons per acre per minute. A number of operators on the Lower Colorado assume the duty to be 7 gallons per acre per minute, and perhaps the same might be assumed for the Brazos. If we do this, we shall obtain for a discharge of 700 cubic feet per second a result indicating that this amount of water would suffice to irrigate about 45,000 acres of rice. Seven hundred cubic feet per second is probably below the average low-stage discharge, as the season covered by the investigations was an unusually dry one. In ordinary years the daily flow would not be likely to fall this low, at any rate for more than a very short period. Still, it is well to know what to expect; but until definite information regarding the duty of water is obtainable any calculations upon the acreage that can be supplied will be but rough approximations.

THE COLORADO RIVER AT WHARTON, TEX.

Below Eagle Lake on both sides of the Colorado River a large acreage has been put under rice, the water being drawn from the Colorado River. Many large pumping plants have been installed and many others have been projected. It is estimated that something like 25,000 acres of rice were watered from the Colorado River in 1901, and the systems then operating in part contemplated an ultimate acreage of about 55,000 acres. Other systems have been projected, and at the present writing some of these are said to have begun preparations for

DIAGRAMS SHOWING CROSS SECTIONS, RATING CURVE, AND DISCHARGE OF COLORADO RIVER AT WHARTON HIGHWAY BRIDGE.





bringing large areas under cultivation. As far as questioned none of the operators along this river seemed to have any doubt of the supply being sufficient for all demands until the summer of 1901 demonstrated that there was a doubt. Prior to this time the gauging stations at Wharton and Richmond had been established—in fact, had been determined upon early in February—and the results of the discharge measurements demonstrate very clearly that the fear of a shortage was well founded in case the systems now being operated in part are completed, to say nothing of new systems, either above or below Wharton. The tabular results given later will show what may be expected during such seasons as that of 1901.

The first discharge measurement was made on June 15 and the last on November 2, 1901. The gauge heights were taken from June 14 to November 3, 1901. On the dates given the following discharge measurements were made:

Measured discharges of the Colorado River at Wharton, Tex.

Date.	Gauge height.	Discharge.	Velocities measured by—
	Feet.	*Cu. ft. per second.*	
June 15, 1901	4.60	1,415	Current meter.
July 24, 1901	6.55	2,663	Do.
August 23, 1901	3.25	615	Do.
November 2, 1901	3.25	635	Do.

Gauge heights were obtained by measuring down from a point near the center of the highway bridge across the Colorado River, the zero of the gauge being taken 50 feet below the top of the guard rail. From the measured discharges and the corresponding gauge heights a rating curve was drawn and is shown in Pl. LXIV.

A rating table was computed from the curve and was used in determining the discharges corresponding to the daily gauge heights.

Rating table for the Colorado River at Wharton, Tex., from June 14, 1901, to November 3, 1901, inclusive.

Gauge height.	Discharge.	Gauge height.	Discharge.	Gauge height.	Discharge.
Feet.	*Cu. ft. per sec.*	*Feet.*	*Cu. ft. per sec.*	*Feet.*	*Cu. ft. per sec.*
3.0	487	4.6	1,415	6.2	2,444
3.1	542	4.7	1,476	6.3	2,512
3.2	597	4.8	1,538	6.4	2,580
3.3	653	4.9	1,600	6.5	2,648
3.4	709	5.0	1,663	6.6	2,717
3.5	766	5.1	1,726	6.7	2,786
3.6	823	5.2	1,789	6.8	2,856
3.7	880	5.3	1,853	6.9	2,926
3.8	938	5.4	1,917	7.0	2,996
3.9	996	5.5	1,981	7.1	3,067
4.0	1,055	5.6	2,046	7.2	3,138
4.1	1,114	5.7	2,112	7.3	3,210
4.2	1,173	5.8	2,177	7.4	3,282
4.3	1,233	5.9	2,244	7.5	3,354
4.4	1,293	6.0	2,310	7.6	3,427
4.5	1,354	6.1	2,377	7.7	3,500

Rating table for the Colorado River at Wharton, Tex., from June 14, 1901, to November 3, 1901, inclusive—Continued.

Gauge height.	Discharge.	Gauge height.	Discharge.	Gauge height.	Discharge.
Feet.	*Cu. ft. per sec.*	*Feet.*	*Cu. ft. per sec.*	*Feet.*	*Cu. ft. per sec.*
7.8	3,574				
7.9	3,648				
8.0	3,722				
8.1	3,979				
8.2	3,872			14.0	8,913
8.3	3,948				
8.4	4,024				
8.5	4,100				
8.6	4,177	12.0	7,019		
8.7	4,254				
8.8	4,331				
8.9	4,409				
9.0	4,488				
9.1	4,566				
9.2	4,645			15.0	9,905
9.3	4,725				
9.4	4,805				
9.5	4,885				
9.6	4,966	13.0	7,942		
9.7	5,047				
9.8	5,128				
9.9	5,210				
10.0	5,292				
11.0	6,136	13.5	8,418		

The following table shows the fluctuations in gauge heights as read at the hour of noon each day. On July 16 the water rose to a height of 15 feet above the zero of the gauge for a short time only. At noon it stood at the height shown in the table for that date:

Gauge heights of the Colorado River at Wharton, Tex.

Day.	1901.					
	June.	July.	August.	September.	October.	November.
	Feet.	*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*
1		3.25	4.45	3.35	5.15	3.25
2		3.20	4.25	3.35	4.75	3.20
3		3.20	4.20	3.25	4.45	3.20
4		3.15	4.15	3.20	4.30	
5		3.10	4.05	3.20	4.20	
6		3.10	4.00	3.15	4.10	
7		3.05	3.95	3.10	3.95	
8		3.00	3.90	3.10	3.85	
9		2.95	3.85	3.10	3.70	
10		3.10	3.75	3.20	3.55	
11		3.15	3.85	3.20	3.85	
12		3.15	3.85	3.25	4.25	
13		3.10	3.65	3.25	4.10	
14	4.55	3.10	3.65	3.25	3.90	
15	4.60	3.05	3.65	3.60	3.75	
16	4.55	13.50	3.55	3.70	3.70	
17	4.55	9.95	3.50	8.20	3.65	
18	4.50	7.65	3.40	8.45	3.55	
19	4.45	7.05	3.35	9.45	3.50	
20	3.95	6.60	3.30	10.45	3.40	
21	3.90	6.45	3.25	9.30	3.35	
22	3.80	8.20	3.35	8.40	3.35	
23	3.70	7.30	3.25	7.35	3.35	
24	3.65	6.55	3.15	6.55	3.35	
25	3.55	6.55	3.05	6.00	3.30	
26	3.50	5.70	3.05	5.55	3.30	
27	3.50	5.50	3.05	5.30	3.30	
28	3.40	5.20	3.05	5.00	3.30	
29	3.35	5.10	3.05	4.90	3.30	
30	3.30	5.00	3.00	5.25	3.25	
31		4.65	3.45		3.25	

The variations in gauge heights are shown graphically in Pl. LXIV. It will be seen by comparison with Pl. LXIII that much greater fluctuations in the water level occurred in the Colorado River at Wharton than took place in the Brazos River at Richmond. Two decided rises occurred in the Colorado River, one in July, the other in September, and the total discharge for the period over which observations extended was considerable. Nevertheless, the water in the river got so low at times that the planters along the river were threatened with a serious shortage, and considerable uneasiness was felt about the supply. For the first half of July and the last week in August the gauge heights averaged but little more than 3 feet, the water falling to 2.95 feet on July 9, the lowest stage of the season. Pl. LXIV also shows, by the alternate light and shaded areas within the curve, how the discharge varied with the gauge heights.

The table following shows the daily discharge in acre-feet. The totals at the bottom give the total monthly discharges for the period covered by the observations.

Discharge of the Colorado River at Wharton, Tex.

Day.	1901.					
	June.	July.	August.	September.	October.	November.
	Acre-feet.	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*
1	....	1,240	2,626	1,351	3,485	1,340
2	....	1,181	2,386	1,351	2,989	1,184
3	....	1,181	2,327	1,240	2,626	1,184
4	....	1,129	2,269	1,184	2,446	....
5	....	1,075	2,150	1,184	2,327	....
6	....	1,075	2,093	1,129	2,210	....
7	....	1,020	2,035	1,075	2,035	....
8	....	966	1,976	1,075	1,918	....
9	....	910	1,918	1,075	1,745	....
10	....	1,075	1,803	1,184	1,575	....
11	....	1,129	1,918	1,184	1,918	....
12	....	1,129	1,918	1,240	2,386	....
13	....	1,075	1,690	1,240	2,210	....
14	2,745	1,075	1,690	1,240	1,976	....
15	2,807	1,020	1,690	1,632	1,803	....
16	2,745	16,697	1,575	1,745	1,745	....
17	2,745	10,415	1,519	7,680	1,690	....
18	2,686	6,871	1,406	8,056	1,575	....
19	2,626	6,014	1,351	9,609	1,519	....
20	2,035	5,389	1,295	11,241	1,406	....
21	1,976	5,185	1,240	9,371	1,351	....
22	1,860	7,680	1,351	7,981	1,351	....
23	1,745	6,367	1,240	6,438	1,351	....
24	1,690	5,322	1,129	5,322	1,351	....
25	1,575	5,322	1,020	4,582	1,295	....
26	1,519	4,180	1,020	3,995	1,295	....
27	1,519	3,929	1,020	3,675	1,295	....
28	1,406	3,548	1,020	3,298	1,295	....
29	1,351	3,423	1,020	3,173	1,295	....
30	1,295	3,298	966	3,612	1,240	....
31	....	2,868	1,464	....	1,240	....
Total	34,325	112,803	50,425	108,162	55,943	3,708

Pl. LXIV shows the variations in the daily discharge from June 14 to November 3, inclusive, and shows an extreme range included between 459 cubic feet per second on July 9 and 8,418 cubic feet per second, by computation, on July 16. A letter received by the writer from an engineer at Eagle Lake states that the discharge of the Colorado River was probably considerably less about the end of the year than at any time covered by the observations.

Pl. LXIV shows the changes in the cross section of the river channel at the gauging station between June 14 and November 2. The three cross-sections given show that the deepest portion of the channel shifted toward the east bank of the river after each of the two rises which appear in the discharge diagrams. An accumulation of drift which made an island of perhaps an acre in extent some few hundred feet below the gauging station may have something to do with this change in the channel.

From July 1 to 15, inclusive, the average daily discharge was a little less than 550 cubic feet per second, the smallest discharge, 459 cubic feet per second, occurring on July 9. From August 24 to 30, inclusive, the average daily discharge was a little less than 520 cubic feet per second, and the average daily discharge from August 16 to September 15, inclusive, was a trifle less than 620 cubic feet per second. The total discharge for the first fifteen days of July amounted to less than the discharge that occurred on the 16th day of the same month.

Assuming for the sake of computation that the duty of water along the Colorado River is 7 gallons per acre per minute (an unsatisfactory way of expressing it, but the one now used by irrigators along the river), we find that 1 cubic foot per second will furnish enough water to irrigate about 65 acres. Therefore, the lowest daily discharge of 459 cubic feet per second, if continued for some time, would suffice to irrigate only about 30,000 acres of rice. The average daily discharge for the first half of July would furnish sufficient water for nearly 36,000 acres of rice. The average daily discharge for the entire month. beginning with August 16 and ending with September 15, would answer for only about 40,000 acres. It would certainly seem that it would be unsafe to count on a larger acreage than this latter amount being served, and yet the writer has received estimates of the acreage below Wharton, for which works are now projected, ranging from 85,000 to 100,000 acres, with probably other projects still in view. If this large amount of land, or any approximation to it, be brought under rice cultivation scarcity of water must inevitably result during seasons of small rainfall. Moreover, it must be remembered that no definite information regarding the amount of water needed per acre is now available. Nor is it likely that the duty of water for rice irrigation when determined for eastern Texas will be an adequate measure of the duty along the Colorado River. The latter is in a region of smaller rainfall and probably has a higher rate of evaporation, so that a lower duty should be expected in the western than obtains in the eastern coast region of the State.

If observations can be continued for two or three more seasons a fairly close approximation to what may be expected in average years should be possible. Meantime planters would do well to go slowly in opening up new lands, lest the capacity of the river be so heavily overtaxed that all the rice farms along the river will be more or less crippled.

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